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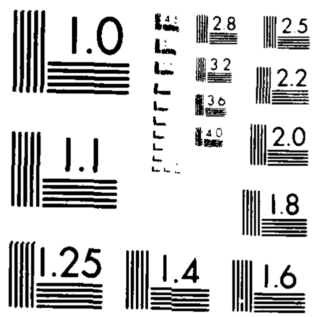

MICROCOPY RESOLUTION TEST CHART

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

COMPUTER PROGRAM
FOR
PRELIMINARY HELICOPTER DESIGN

by

Michael W. Rogers

September 1983

Thesis Advisor Donald M. Layton

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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fixed wheel, and retractable wheel. By comparing the power required for each configuration, the user can determine the optimum landing gear for the design.

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Computer Program for Preliminary Helicopter Design

by

Michael W. Rogers
Captain, United States Army
B.S., United States Military Academy, 1974

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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September 1983

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ABSTRACT

This report gives the operator of the Hewlett-Packard (HP-41) handheld calculator the ability to quickly and accurately determine the power requirements of a helicopter in the preliminary design phase. These power requirements are computed for three landing gear configurations: skid, fixed wheel, and retractable wheel. By comparing the power required for each configuration, the user can determine the optimum landing gear for the design.

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I wish to express my sincere appreciation to Professor Donald Layton for his guidance and assistance during the preparation of this thesis. I also wish to thank Mr. Ron Shinn from the Army Aviation Research and Development Command's Advanced Systems Branch, for his assistance in this project. The information he provided concerning the computation of landing gear data proved invaluable.

I. INTRODUCTION

A. BACKGROUND

The design process for any aircraft is a tedious, often repetitive procedure, and for a Helicopter, all complexities are compounded. In order to facilitate the design process, computer programs have been derived that will replace long calculations with a speedy solution to many of the problems. These programs, however, are generally quite lengthy and are not amenable to an educational conceptual design project, or to 'quick looks' at proposed decisions.

Two aids to the determination of helicopter performance and/or helicopter design have been developed in the Department of Aeronautics at the Naval Postgraduate School. These are the series of programs for the HP-41 handheld computer [Ref. 1] and the Helicopter Conceptual Design Manual [Ref. 2] which uses these programs.

None of these programs relate to the landing gear of the helicopter, even though such programs are necessary in order to determine the most advantageous landing gear configuration for a particular design.

B. GOALS

The initial goal of this project was to develop a series of programs for the handheld HP-41 computer which would enable the student to determine which landing gear configuration best complements his design. In the course of

accomplishing this goal, it became apparent that numerous additional programs, written from the Helicopter Design Manual, would be required. A second goal was therefore established; to program the design course in such a way that the student could accomplish his required tasks without the mundane iterative calculations required in a design procedure. If hand calculations were required, instructors could rapidly check the student's work with these programs.

Mr. Ronald Shinn, from the Advanced Systems Branch, Army Aviation Research and Development Command, provided an additional goal. Inasmuch as a definite need exists for the design engineer to be able to quickly and inexpensively derive a design that is fairly accurate in the preliminary design phase, a third goal was established; to obtain an output from the programs which is, on average, within ten percent of the Advanced Systems Branch large scale computer program output.

A final goal was to design the programs in such a way as to eliminate the necessity for the student or design engineer to refer to charts and graphs for the necessary input information. Thus, the programs are designed to be "self-contained."

II. APPROACH TO THE PROBLEM

A. BASIC LINE OF APPROACH

A series of programs were written for the HP-41, which would output the horsepower required at various airspeeds and altitudes for a helicopter with skid, fixed wheel, or retractable type landing gear. From these power outputs, a graph can be plotted which will indicate the crossover point, i.e., where the retractable gear, with its additional weight and reduced drag, will require less power than the skid or fixed wheel configured aircraft. Thus, depending on the average environment of the helicopter in question, a determination can be made as to which type of landing gear would contribute the most to the design.

B. DETAILED LINE OF APPROACH

As stated in section 1B, one goal of this project was to eliminate, as much as possible, the use of graphs and charts to provide the necessary inputs when utilizing the programs. With this objective in mind, Chapters Two and Three of the Helicopter Design Manual were programmed. The Chapter Two program, entitled MR (Main Rotor), does not deviate from the design manual. By inputting the specification weight, rotor radius, critical Mach number, and maximum forward velocity, the program displays the maximum rotor tip velocity, disk loading, rotational velocity, coefficient of thrust, solidity,

chord length, aspect ratio, and coefficient of lift. The user is then prompted as to whether the value inputted for Rotor Radius, R, is satisfactory (i.e., are the displayed values within prescribed limits? A reduction in rotor radius will increase disk loading, decrease aspect ratio, and increase rotational velocity.) If a new value for R is not needed, the Chapter Three program, entitled PHV, (Power to Hover), is executed. This program computes the power to hover out of and in ground effect. The subroutine "FM," (Figure of Merit), is then executed from the PHV program. If the Figure of Merit is within limits (.7 to .8), the subroutine "WT," (Weight). is executed. If, however, "FM" is out of limits, the program prompts the user as to whether the value is high, in which case the subroutine "CHD," (Chord), is executed, or low (subroutine "RV," (Rotational Velocity), is executed).

The "WT" subroutine (using sixty percent of the specification gross weight as a first approximation for empty weight) computes a second approximation of the empty weight using the equations found in the Weight Estimating Relationships [Ref. 3]. To this empty weight are added fuel, useful load, and landing gear weight.

For the first iteration, a skid gear weight is added and is used as a case for future landing gear computations. The take-off gross weight is displayed and the user is prompted as to whether this weight is satisfactory (i.e., if enough allowance is made for the additional weight of the fixed and

retractable type landing gears, keeping in mind the maximum allowable gross weight specified for the design). If the weight is not satisfactory, the WT program uses the second approximation of empty weight as a base and re-computes the take-off gross weight as before. If this value is satisfactory, the MR, PHV, and associated subroutines are re-executed using this new gross weight approximation. If all displayed values are still within specifications, the program prompts the user to clear certain programs from computer memory and to input other programs. This must be done due to the limited number of storage registers available in the HP-41. The inputted programs are PTOT, PCOMP, and ESHP; (Power Total, Compressibility Power, and Equivalent Shaft Horsepower, respectively).

Three PTOT programs have been written. One is designed specifically for use with the HP 82143A printer. The output is automatic and consists of a velocity and the equivalent shaft horsepower required at that speed. A second program outputs only the ESHP required for an inputted velocity (no printer required). The third program may be used with or without the printer and displays all of the individual powers that comprise the ESHP for a specified velocity.

The subroutines EFPA, PCOMP, and ESHP are used in the main program PTOT. EFPA computes the effective flat plate area of the design helicopter. This value is determined from the aircraft gross weight, its landing gear configuration and

whether the aircraft, in the opinion of the user, has clean or dirty lines. PCOMP computes the additional horsepower required due to compressibility effects while ESHP computes the extra power needed due to accessories, transmission losses, and losses due to multiple engine installation.

Once PTOT has been executed and the data recorded, the user re-executes the WT program. Since the skid landing gear is to be used as a base for determining the weight of the fixed and retractable gear, the program automatically bypasses the component weight calculations, thereby allowing the identical empty weight to be used. The user inputs the same values for fuel and useful load weight. Following the calculator prompts, the user inputs fixed gear information. The new take-off gross weight is computed and the program transfers to PTOT. The reader will recall that during the first iteration of the WT program (using skid gear information), the MR program was re-executed to insure that the newly computed value of gross weight did not result in specification violations. The additional weight of the fixed and retractable landing gear results in less than a four percent increase in the total gross weight of the aircraft. It is therefore not necessary to again check the MR values, for this small increase in gross weight will not result in specification violations. After obtaining the power outputs with the fixed landing gear, re-execute the WT program, inputting retractable landing gear data. Once the three data sets have

been computed, it is a simple matter to compare these lists to determine the crossover points.

For a graphical display of the crossover points, two programs have been developed: MYPLOT and POWERPLO [Ref. 4]. These programs are compatible with the TEXTRONICS/DISSPLA package.

III. RESULTS AND CONCLUSIONS

This series of programs allows the user to quickly and accurately determine the power required of a helicopter at any speed, and at any altitude. The user is able to determine the most advantageous landing gear configuration for his design depending on the projected mission environment of the aircraft.

In an attempt to display the accuracy of these programs, three sample problems are solved in Appendix B. The first is a step-by-step cargo helicopter design problem. The second is an attempt to design a current production helicopter, the Hughes AAH-64, and compare the actual power outputs with the HP-41 program outputs. The third problem compares the Army Aviation Research and Development Command's Advanced System's computer power outputs with that of the HP-41 program outputs given the identical input data.

Though accurate, inexpensive, and rapidly executed, it must be emphasized that these programs represent only the "back of the envelope" phase of preliminary design. Further detailed analysis currently requires the use of expensive main frame computers.

APPENDIX A

HP-41 COMPUTER PROGRAM

MAIN ROTOR (MR)

1. PURPOSE

This program represents the Second Chapter in the Helicopter Design Manual. It computes the disk loading (DL), rotational velocity (PV), coefficient of thrust (CT), solidity (SD), chord length (c), aspect ratio (AR), coefficient of lift (CL), and the maximum rotor blade tip velocity V(TIP) given the following inputs:

A) Specification Weight (Spec Wt): the absolute maximum gross weight allowable.

B) Main Rotor Radius (R): this is an educated guess. Start by using the design maximum radius allowed.

C) Critical Mach Number (Mch Crit): to prevent the rotor blade from encountering undesirable compressibility effects, use the historically acceptable value of .65.

D) Maximum Forward Velocity (VF Max): input the design's maximum forward velocity.

Throughout all of these programs, when prompted for a Yes or No answer, the user should input a 1 for Yes, and a 0 for No.

2. EQUATIONS

```
DL=(GW)/((PI)*R**2)   where the first approximation
                      of GW = (Spec Wt) * .8
```

VT(max)ssl = (Mch Crit) * (a) where a =
Sqrt(Gamma * g * R * T)

RV=VT(Max)/(R)

CT=(GW)/(A * RHO * VT(Max)**2)

SD=(CT/(BL)
where BL=((-.16667)*(VF Max/.59248)/VT Max) + .15515

Note: The blade loading calculation is derived from a chart of blade loading vs. advanced ratio. The chart is linear for an advanced ratio (VF Max)/(VT Max) of > .35. The equation for a straight line (y=mx+b) was therefore used for this approximation.

c= (SD * PI * R)/b

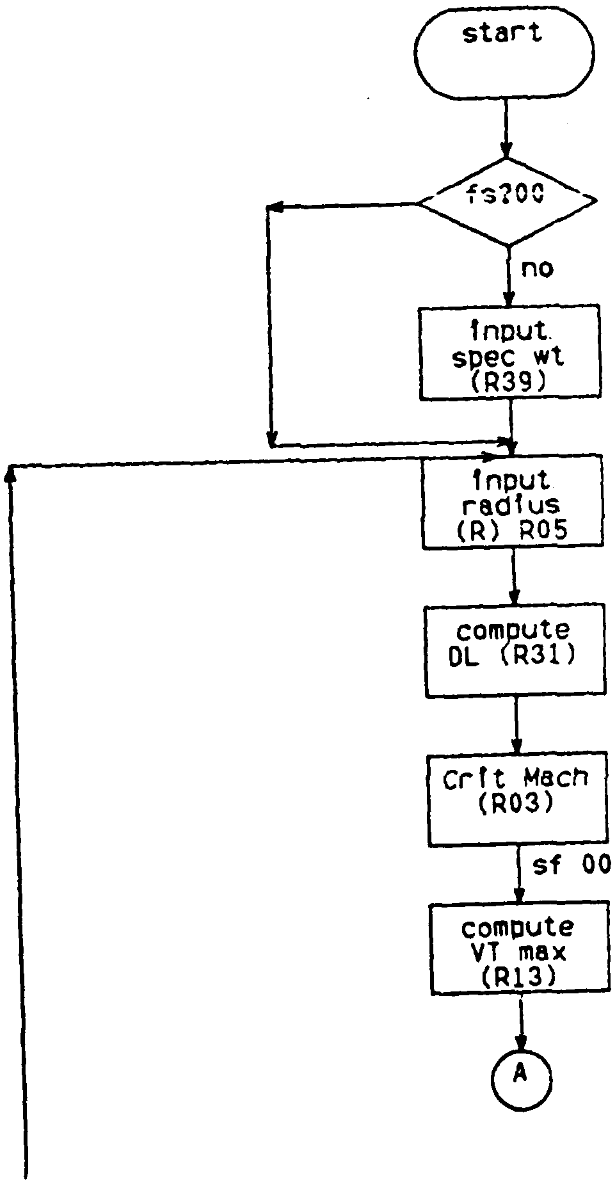
AR=(R)/c

CL= (6 * CT)/SD

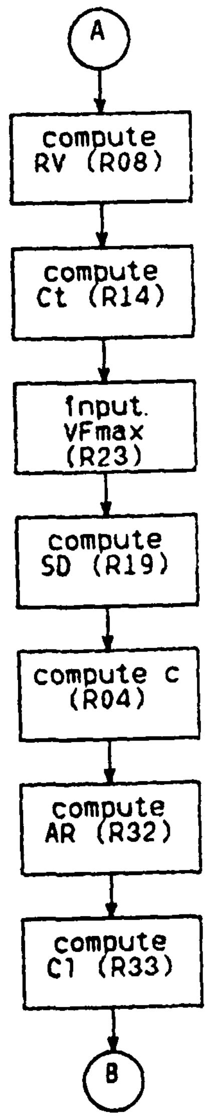
where:

DL = disk loading	GW = gross weight
R = radius of the main rotor	VT(Max) = blade maximum tip velocity
RV = rotational velocity	CT = coefficient of thrust
RHO = density altitude	SD = solidity
BL = blade loading	b = no. of main rotor blades
c = chord (main rotor)	AR = aspect ratio
CL = coefficient of lift	A = Area of main rotor

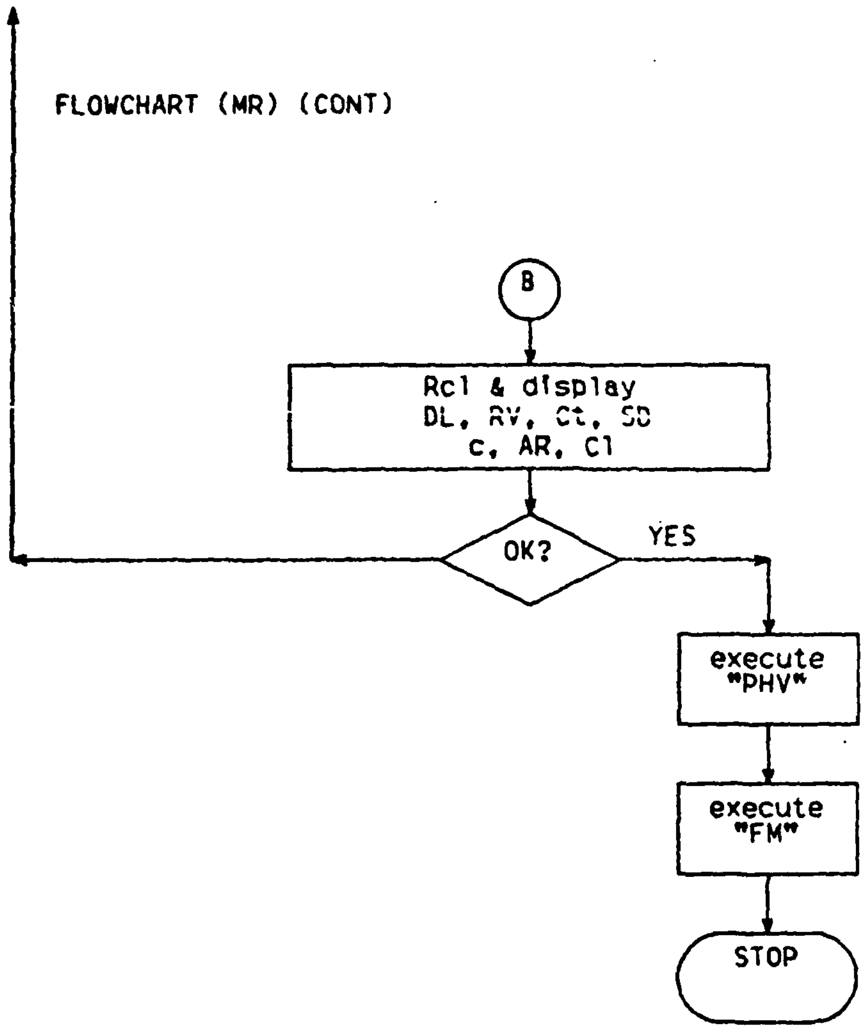
3. FLOWCHART (MR)



FLOWCHART (MR) (CONT)



FLOWCHART (MR) (CONT)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS

A helicopter is to be designed with the following specifications:

VF(Max) = 160 kts

(Spec Wt) = 18000 lbs

Maximum Rotor Diameter = 58 ft

AR must be between 15 and 25 and DL must be less than 7.5.

Compute DL, RV, CT, SD, c, AR, and CL.

Input the MR (Main Rotor) program and clear all flags.

KEYSTROKES		DISPLAY
XEQ (alpha) SIZE (alpha)		SIZE...
068 XEQ (alpha) MR (alpha)		Spec Wt=?
18000	(r/s)	R=?
29	(r/s)	Mch Crit=?
0.65	(r/s)	VT MX=725.63
	(r/s)	VF MX=?
160	(r/s)	DL=5.45
	(r/s)	RV=25.02
	(r/s)	CT=.004
	(r/s)	SD=.047
	(r/s)	c=1.065
	(r/s)	AR=27.23
	(r/s)	CL=.559
	(r/s)	R ok?
0	(r/s)	

If these values are not within specifications, push (r/s) and input a new value of R. Since flag 00 is now set, the program automatically goes to R=? Because AR is rather high, input a new value of 27 feet for R. Proceeding as before, the following data is displayed.

KEYSTROKES	DISPLAY
(r/s)	DL=6.28
(r/s)	RV=26.87
(r/s)	CT=.005
(r/s)	SD=.054
(r/s)	c=1.144
(r/s)	AR=23.6
(r/s)	CL=.559
(r/s)	R ok?
1 (r/s)	

By decreasing the rotor radius, the aspect ratio was decreased while disk loading was increased. Both values are now within the specifications. Because 1 was inputted for the prompt (R ok?), the program automatically advances to the PHV program.

5. PROGRAM LISTINGS

```
01♦LBL "MR"
02 FS? 55
03 CF 21
04 FIX 3
05 FS? 00
06 GTO "BB"
07 "SPEC WT=?"
08 PROMPT
09 STO 39
10 .8
11 *
12 STO 36
13♦LBL "BB"
14 .00237696
15 ENTER↑
16 STO 11
17 "R=?"
18 PROMPT
19 STO 05
20 X↑2
21 PI
22 *
23 STO 12
24 RCL 36
25 X<>Y
26 /
27 STO 31
28 "MCH CRIT="
29 PROMPT
30 STO 03
31 288.15
32 ENTER↑
33 401.8
34 *
35 SQRT
36 *
37 .3048
38 /
39 STO 13
40 "VT MX="
41 ARCL X
42 AVIEW
43 STOP
44 RCL 13
45 RCL 05
46 /
47 STO 08
48 SF 00
49 RCL 12
50 RCL 11
51 *
52 RCL 13
53 X↑2
54 *
55 RCL 36
56 X<>Y
57 /
58 STO 14
59 "VF MX=?"
60 PROMPT
61 .59248
62 /
63 STO 23
64 RCL 13
65 /
66 .166667
67 CHS
68 *
69 .15515
70 +
71 RCL 14
72 X<>Y
73 /
74 STO 19
75 PI
76 *
77 RCL 05
78 *
79 4
80 /
81 STO 04
82 RCL 05
83 X<>Y
84 /
85 STO 32
86 RCL 14
87 5
88 *
89 RCL 19
90
91 STO 33
92♦LBL "AA"
93 RCL 31
94 "DL="
95 ARCL X
96 AVIEW
97 STOP
98 RCL 08
99 "RV="
100 ARCL X
101 AVIEW
102 STOP
103 RCL 14
104 "CT="
105 ARCL X
106 AVIEW
107 STOP
108 RCL 19
109 "SD="
110 ARCL X
111 AVIEW
112 STOP
113 RCL 04
114 "C="
115 ARCL X
116 AVIEW
117 STOP
118 RCL 32
119 "AR="
120 ARCL X
121 AVIEW
122 STOP
123 RCL 33
124 "CL="
125 ARCL X
126 AVIEW
127 STOP
128 "R OK?"
129 PROMPT
130 X>0?
131 XEQ "PHV"
132 GTO "BB"
133 END
```

POWER TO HOVER (PHV)

1. PURPOSE

This program computes the power required to hover in and out of ground effect at SSL. This program is to be run following satisfactory completion of the MR program. A subroutine entitled "FM" is used to calculate the Figure of Merit for the aircraft. If the Figure of Merit does not fall within prescribed limits, the subroutine chord (CHD), or rotational velocity (RV), will automatically be executed.

The following are required inputs for PHV.

A) Number of main rotor blades.

B) Coefficient of drag of the main rotor, (Cdo).

C) Height of the main rotor above the ground, (H).

2. EQUATIONS

B(MR)=1-[(2 * CT(MR))**.5/b(MR)]

Pi(MR)=(1/B) * [(GW)**1.5/(2 * RHO * A)**.5]

Po(MR)=((SD)*(Cdo)*(RHO)*(A)*(VT)**3)/4400

Pt=(OGE)=Pi + Po

P/P(OGE)=-0.1276*(H/(2*R)**4)+.7080*(H/(2*R)**3)

-1.4569*(H/(2*R)**2)+1.3432*(H/2*R))+.5147

Pt(IGE)=Po(MR) + P/P(OGE) + Pi(MR)

where:

B is the tip loss factor.

A is the area of the main rotor disk.

Pi is the induced power (with tip loss).

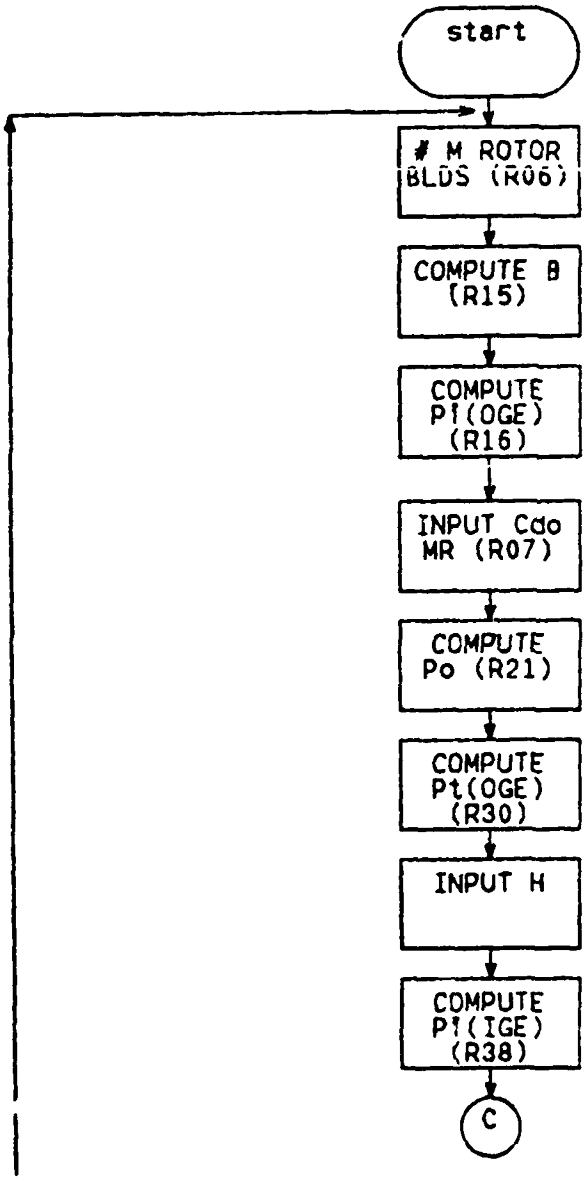
Cdo is the coefficient of drag for the main rotor (at zero lift).

Po is the profile power.

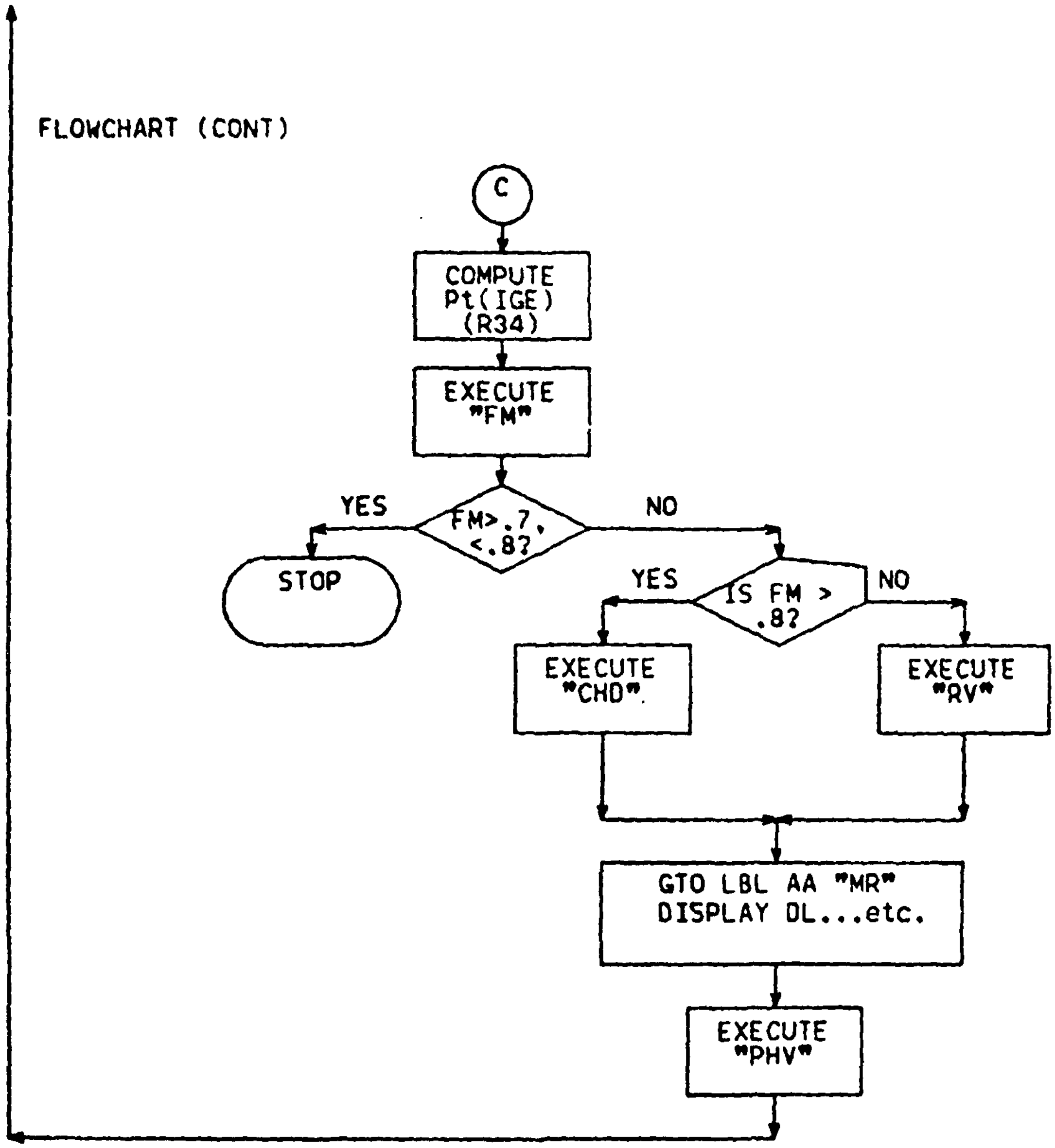
Pt(OGE) is the total power to hover out of ground effect.

Pt(IGE) is the total power to hover in ground effect.

3. FLOWCHART


start
M ROTOR BLDS (R06)
COMPUTE B (R15)
COMPUTE Pi(OGE) (R16)
INPUT Cdo MR (R07)
COMPUTE Po (R21)
COMPUTE Pt(OGE) (R30)
INPUT H
COMPUTE Pi(IGE) (R38)
C

FLOWCHART (CONT)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS:

Following a satisfactory run of "MR," determine the power to hover out of and in ground effect and the Figure of Merit for the helicopter.

Specifications:

Number of main rotor blades = 4

Coefficient of Drag (Cdo) of the main rotor = .01

Height of the main rotor above the ground = 14.4 ft

KEYSTROKES		DISPLAY
(XEQ)	(alpha) PHV (alpha)	NO. MR BLDS=?
4	(r/s)	Cdo MR=?
0.01	(r/s)	Pth OGE=1232
	(r/s)	H=?
14.4	(r/s)	Pth IGE=1019
	(r/s)	FIG MER=0.74
	(r/s)	FM ok?
1	(r/s)	WE=1080

5 PROGRAM LISTINGS

```
01♦LBL "PHY"
02 FIX 0
03♦LBL "TL"
04 RCL 14
05 2
06 *
07 SQRT
08 "NO.MR BLDS=?"
09 PROMPT
10 STO 06
11 /
12 CHS
13 1
14 +
15 STO 15
16♦LBL "PI"
17 RCL 11
18 RCL 13
19 *
20 2
21 *
22 SQRT
23 RCL 36
24 ENTER↑
25 1.5
26 Y↑X
27 /
28 1/X
29 RCL 15
30 /
31 550
32 /
33 STO 16
34♦LBL "PO"
35 RCL 13
36 3
37 Y↑X
38 RCL 12
39 *
40 RCL 11
41 *
42 "CdO MR=?"
43 PROMPT
44 STO 07
45 *
46 RCL 19
47 *
48 4400
49 /
50 STO 21
51♦LBL "PT"
52 RCL 21
53 RCL 16
54 +
55 STO 30
56 "PTH OGE="
57 ARCL X
58 AVIEW
59 STOP
60♦LBL "PT IGE"
61 "H=?"
62 PROMPT
63 STO 09
64 2
65 /
66 RCL 05
67 /
68 STO 17
69 4
70 Y↑X
71 .1276
72 *
73 CHS
74 RCL 17
75 3
76 Y↑X
77 .7080
78 *
79 +
80 RCL 17
81 2
82 Y↑X
83 1.4569
84 *
85 -
86 RCL 17
87 1.3432
88 *
89 +
90 .5147
91 +
92 RCL 16
93 *
94 STO 38
95 RCL 21
96 +
97 STO 34
98 "PTH IGE="
99 ARCL Y
100 AVIEW
101 STOP
102 XEQ "CM"
103 END
```

WEIGHT (WT)

1. PURPOSE

This program uses an iterative procedure to compute a more accurate estimate of the empty weight and total gross weight of the helicopter.

The program makes a "1st cut" estimate of the empty weight (WE) by multiplying the specification weight by .6. This WE is then used to compute the weight of the blades, hub, fuselage, controls, electrical and fixed equipment. The weight of the propulsion system is estimated by recalling R30 (Pth(OGE)) and multiplying by 1.2. These values are then added together and represent the second empty weight estimate (WE2). To estimate the total gross weight, fuel, useful load, and landing gear weight are added to the empty weight figure. Three types of landing gear are considered; skid, fixed wheel, and retractable wheel. A common practice among aircraft designers is to add two pounds to the gross weight of the aircraft for every additional pound added as a result of heavier equipment being installed. This is due to the fact that one additional pound requires more power which results in more fuel usage. In this case, the skid is lighter than the fixed wheel gear which, in turn, is lighter than the retractable gear.

This gross weight estimate is calculated as follows: the skid gear weight is calculated and is used as a reference point. This weight is subtracted from the fixed wheel gear

weight. An identical procedure occurs for the retractable gear. In this manner, every extra pound due to the addition of a heavier landing gear results in two extra pounds being added to the gross weight of the aircraft.

The formulas for computing the landing gear weight use the specification weight (absolute maximum weight allowed). If the user desires to incorporate a "buffer" to insure a satisfactory performance of the landing gear during a hard landing, this weight should be increased by a suitable percentage.

2. EQUATIONS

```
Wb=(.06)*(WE)*(R**.4)*(SD)**.33

Wh=(.0135)*(WE)*(R**.42)

Wp=(0.21)*Pth(OGE)

Wf=(0.21)*(WE)

Wc=(0.06)*(WE)

We=(0.06)*(WE)

Wq=(0.28)*(WE)

Weight of the skid gear=(.0245*(Spec Wt)**.8606)
                        *(FL)**.8046

Weight of fixed and retractable landing gear=40.0*
                        (WMTO)**.6662 * (NW)**.536
                        *(IRLG)**.1198
```

where:

Wb is the total weight of the blades.

Wh is the weight of the hub.

Wp is the weight of the propulsion system.

Wf is the weight of the fuselage.

Wc is the weight of the flight controls.

We is the weight of the aircraft's electrical equipment.

Wq is the weight of the installed fixed equipment.

WE2 is the empty weight (the sum of the above).

R is the main rotor radius.

SD is the main rotor solidity.

Pth(OGE) is the power to hover out of ground effect (recalled from R30).

FL is a coefficient. If the main rotor has two blades, the program uses a value of 2. If more than 2, FL=4.

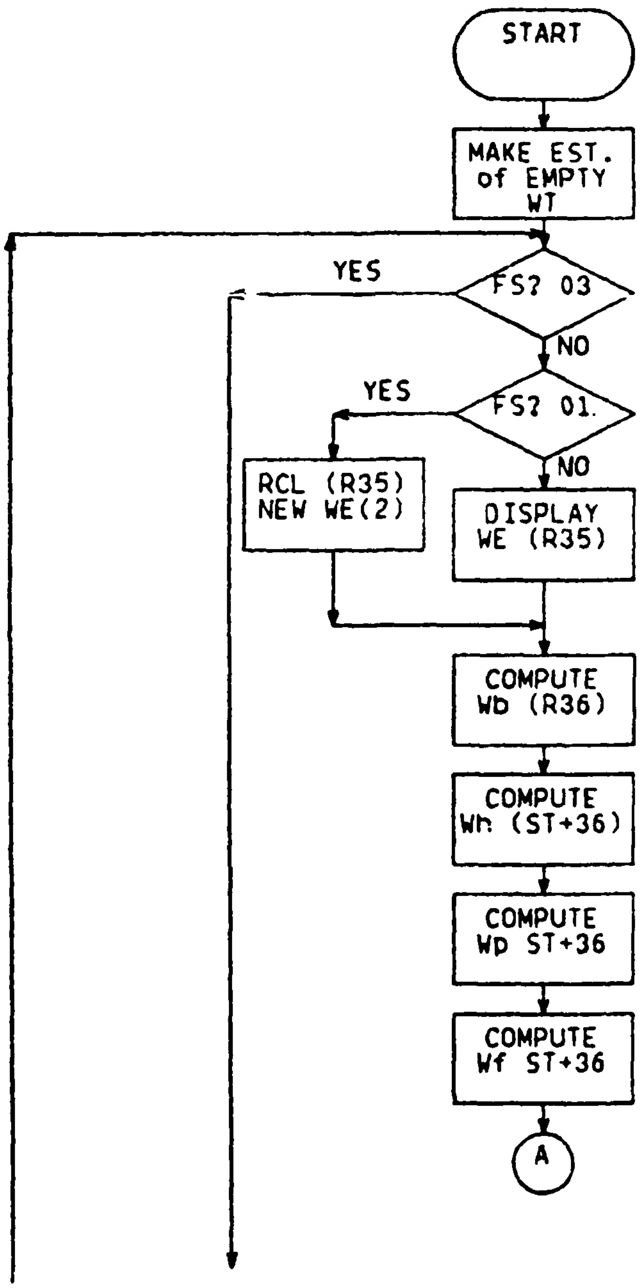
WMTO is the specification weight divided by one thousand.

NW is the number of landing gears.

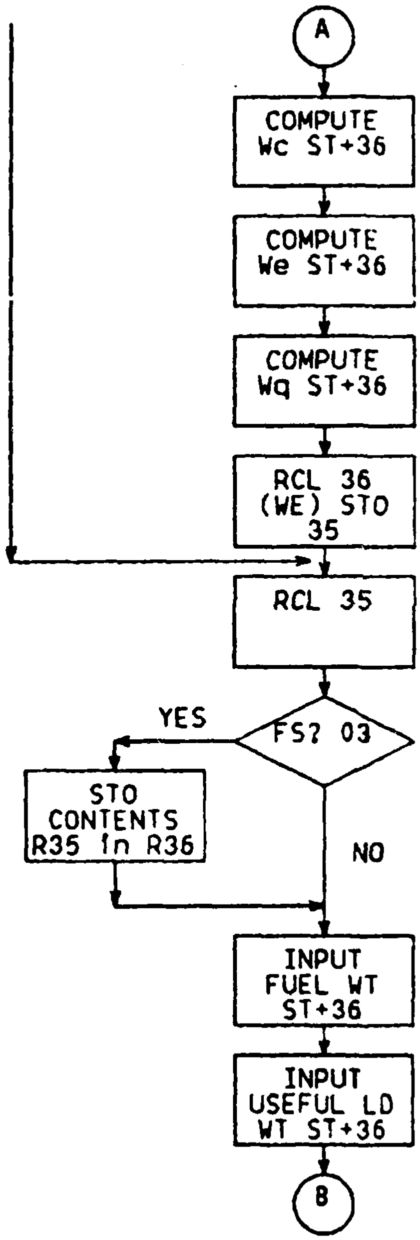
IRLG is the retractable gear flag (1=fixed,2=retractable).

Mr. Ronald Shinn developed the equation for skid gear weight. Most designers use 2% of GW to determine skid weight. In an effort to achieve a more accurate equation, he used a multiple regression routine to arrive at his equation. This formula has an 11% error when compared against the skid weight of eight operational helicopters. The equation used to determine the fixed and retractable landing gear weights had an 8.5% error when compared with 29 operational aircraft.

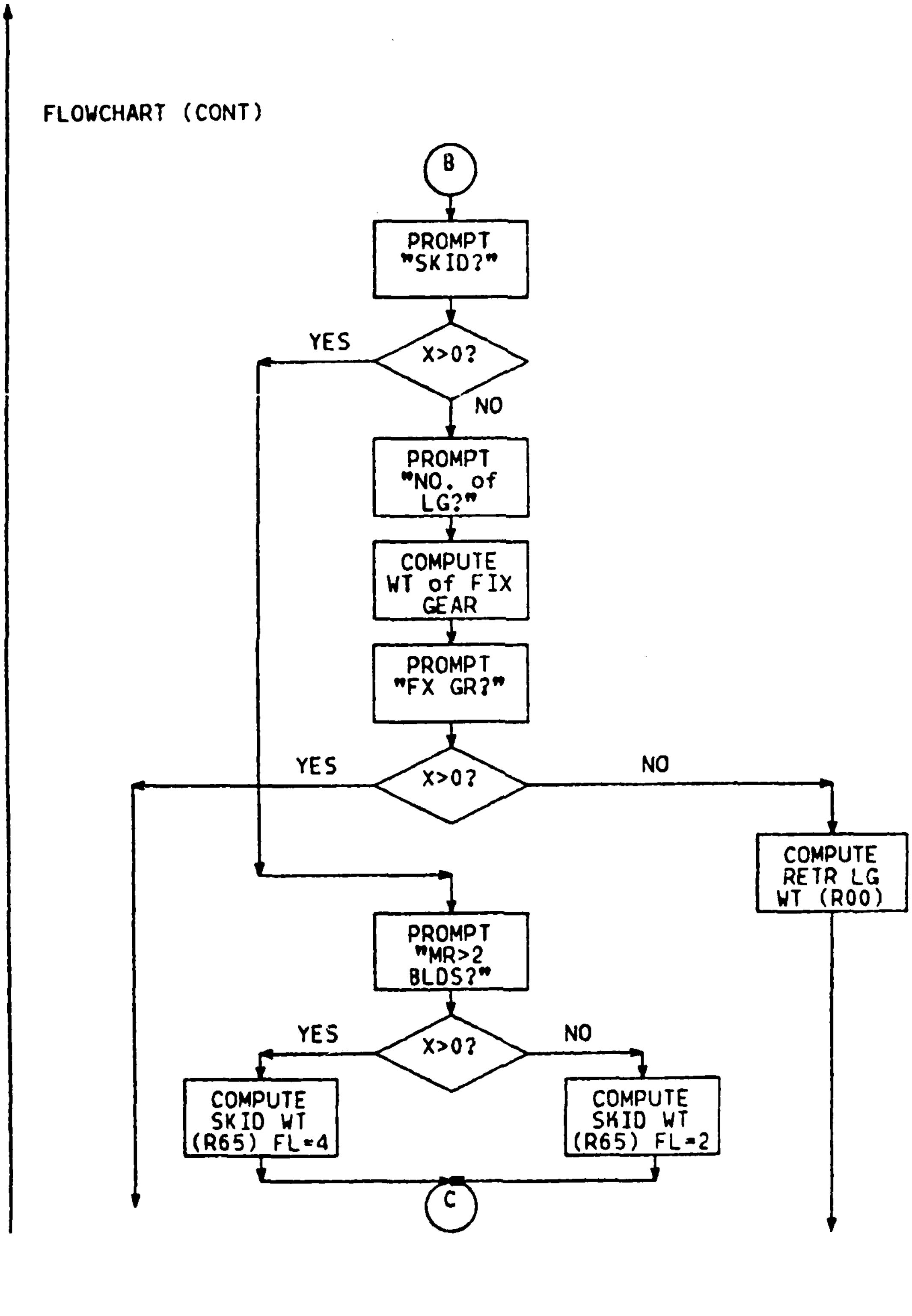
3. FLOWCHART


START
MAKE EST. of EMPTY WT
YES
FS? 03
NO
YES
FS? 01
NO
RCL (R35) NEW WE(2)
DISPLAY WE (R35)
COMPUTE Wb (R36)
COMPUTE Wh (ST+36)
COMPUTE Wp ST+36
COMPUTE Wf ST+36
A

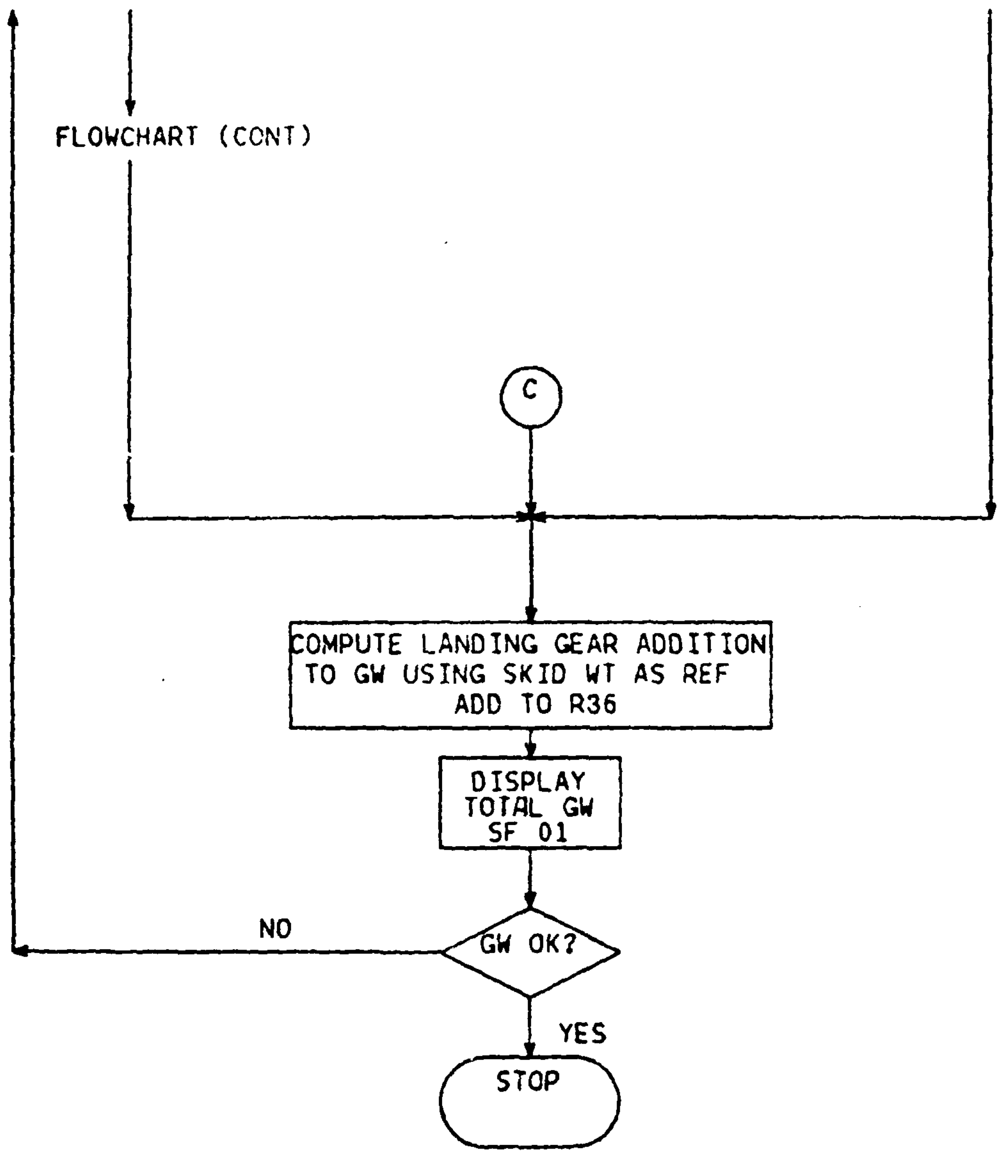
FLOWCHART (CONT)



FLOWCHART (CONT)



FLOWCHART (CONT)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS

The user will note that at the conclusion of the PHV example problem, the program transferred automatically to the WT program (WE=10800.00 was displayed). If this value is in the calculator display window, disregard the initial key stroke instruction.

KEYSTROKES	DISPLAY
XEQ (alpha) WT (alpha)	WE=10,800
(r/s)	Wb=924.0
(r/s)	Wh=582.01
(r/s)	Wp=1477.99
(r/s)	Wf=2268.00
(r/s)	Wc=648.00
(r/s)	We=648.00
(r/s)	Wq=3024.00
(r/s)	WE 2 =9572.01
(r/s)	W FL?
4000 (r/s)	USE LD?
3750 (r/s)	SKID?
1 (r/s)	MR>2 BLDS?
1 (r/s)	T GW=17665.30

At this point, push the (r/s) button. The computer will prompt, "WT OK?" If the weight is far enough below the specification weight to allow room for the added weight of the fixed and retractable landing gear, input 1 (Yes). Input

0 (No), otherwise. If this second option is taken, the computer displays the most recently computed value of empty weight and uses this as a base for iteration. For this example problem, perform an additional iteration.

KEYSTROKES		DISPLAY
	(r/s)	WT OK?
0	(r/s)	WE=9572.01
	(r/s)	Wb=818.94
	(r/s)	Wh=515.83
	(r/s)	Wp=1477.99
	(r/s)	Wf=2010.12
	(r/s)	Wc=574.32
	(r/s)	We=574.32
	(r/s)	Wq=2680.16
	(r/s)	WE 2 =8651.69
	(r/s)	W FL?
4000	(r/s)	USE LD=?
3750	(r/s)	SKID?
1	(r/s)	MB>2 BLDS?
1	(r/s)	T GW=16744.99
	(r/s)	WT OK?
1	(r/s)	

The program transfers back to the MR program. This newly computed value of gross weight is now used to obtain the MR output. The user must again check to insure all values are within prescribed specifications.

5. PROGRAM LISTING

```
01♦LBL "WT"
02 CF 05
03 FIX 2
04 FS? 55
05 CF 21
06 RCL 39
07 .6
08 *
09♦LBL 01
10 FS? 03
11 GTO 02
12 FS? 01
13 RCL 35
14 "WE="
15 ARCL Y
16 AVIEW
17 STOP
18 STO 35
19 RCL 05
20 .4
21 Y↑X
22 *
23 .06
24 *
25 RCL 19
26 .33
27 Y↑X
28 *
29 STO 36
30 "Wb="
31 ARCL Y
32 AVIEW
33 STOP
34 RCL 35
35 .0135
36 *
37 RCL 05
38 .42
39 Y↑X
40 *
41 ST+ 36
42 "WH="
43 ARCL Y
44 AVIEW
45 STOP
46 RCL 30
47 1.2
48 *
49 ST+ 36
50 "WP="
51 ARCL Y
52 AVIEW
53 STOP
54 RCL 35
55 .21
56 *
57 ST+ 36
58 "WF="
59 ARCL Y
60 AVIEW
61 STOP
62 RCL 35
63 .06
64 *
65 ST+ 36
66 "WC="
67 ARCL Y
68 AVIEW
69 STOP
70 RCL 35
71 .06
72 *
73 ST+ 36
74 "We="
75 ARCL Y
76 AVIEW
77 STOP
78 RCL 35
79 .28
80 *
81 ST+ 36
82 "WA="
83 ARCL Y
84 AVIEW
85 STOP
86 RCL 36
87 "WE 2="
88 ARCL Y
89 AVIEW
90 STOP
91 STO 35
92♦LBL 02
93 RCL 35
94 FS? 03
95 STO 36
96 "W FL?"
97 PROMPT
98 ST+ 36
```

```
 99 "USE LD?"
100 PROMPT
101 ST+ 36
102 "SKID?"
103 PROMPT
104 X>0?
105 GTO 04
106 RCL 39
107 1000
108 /
109 .6662
110 Y↑X
111 STO 00
112 "NO. LG?"
113 PROMPT
114 .536
115 Y↑X
116 ST* 00
117 40
118 ST* 00
119 RCL 00
120 STO 66
121 "EX GR?"
122 PROMPT
123 X>0?
124 GTO 07
125 2
126 ENTER↑
127 .1198
128 Y↑X
129 ST* 00
130 RCL 00
131 GTO 08
132♦LBL 04
133 "MR>2 BLDS?"
134 PROMPT
135 X>0?
136 GTO 05
137 2
138 ENTER↑
139 .8046
140 Y↑X
141 RCL 39
142 .8606
143 Y↑X
144 *
145 .0245
146 *
147 STO 65
148 GTO 09
149♦LBL 05
150 4
151 ENTER↑
152 .8046
153 Y↑X
154 RCL 39
155 .8606
156 Y↑X
157 *
158 .0245
159 *
160 STO 65
161 GTO 09
162♦LBL 07
163 RCL 66
164 RCL 65
165 -
166 2
167 *
168 RCL 66
169 +
170 GTO 09
171♦LBL 08
172 RCL 00
173 RCL 65
174 -
175 2
176 *
177 RCL 00
178 +
179♦LBL 09
180 ST+ 36
181 RCL 36
182 "T GW="
183 ARCL X
184 AVIEW
185 STOP
186 FS? 03
187 XEQ "PTOT"
188 SF 01
189 "WT OK?"
190 PROMPT
191 X=0?
192 GTO 01
193 SF 04
194 XEQ "MR"
195 END
```

TOTAL POWER (PTOT)

1. PURPOSE

Three PTOT programs were written. The first program was designed specifically for use with the HP82143A printer. The printer outputs the velocity and corresponding engine shaft horsepower required. The second PTOT program was designed for the user who does not have access to the HP printer. This program displays the engine shaft horsepower required at an inputted velocity. The third program displays, for an inputted velocity, all of the individual powers required, for both main and tail rotors, the total power required and the engine shaft horsepower required. This program can be used with or without the printer. Because of the detail involved with this program, execution is much slower than with the other two programs.

2. EQUATIONS

```
Pp(mr fwd)=(0.5)*rho*V(fwd)**3*EFPA(ff)

Vi(mr hover)=(GW/(2*rho*A))**.5

Pi(mr fwd)=GW(-(V(fwd)**2/Vi(hover)**2)/2
           ((V(fwd)**2/(2*Vi(hover)**2)+1
           **.5))**.5 * Vi(hover)

Po(mr hover)=(SIGMA(mr) * Cdo(mr) * rho * A(mr)
           * V(mr tip)**3)/4400

MU(mr)=V(fwd) / V(mr tip)

Po(mr fwd)=(1+4.3*MU**2) * Po(mr hover)

Pt(mr fwd)=Po(mr fwd) + Pp(mr fwd) + Pi(mr fwd)

Mach Tip(mr)= (V(fwd) + V(mr tip)) /
              (gamma * g * R * T)**.5
```

```
R(tr)=(GW / 1000)**.5 * 1.3

L(tail)=R(tr) + R(mr) + .5

Chord(tr)=R(tr) / AR(tr)

T(tr)=Pt(mr hover oge) / (RV(mr) * L(tr)

A(tr)=R(tr)**2 * PI

V(tr tip)=RV(mr) * 4.5 * R(tr)

CT(tr)=T(tr) / (A(tr) * rho * V(tr tip)**2)

B(tr)=1-((2 * CT(tr))**.5 / b(tr))

Pi(tr tl hover)= (1 / B(tr)) * (T(tr)**1.5 /
                 (2 * rho * A(tr))**.5)

SIGMA(tr)=(b(tr) * C(tr)) / (R(tr) * PI)

Po(tr hover)=(SIGMA(tr) * Cdo(tr) * rho * A(tr) *
              V(tr tip)**3)/4400

Pt(tr hover)=Po(tr) + Pi(tr tl)

MU(tr)=V(fwd) / V(tr tl)

Po(tr fwd)=Po(tr hover) * (1 + 4.3 * MU(tr)**2)

T(tr fwd)=Pt(mr fwd) / (RV(mr) * L(tr))

CT(tr fwd)=T(tr fwd) / (A(tr) * rho * V(tr tip)**2)

B(tr fwd)=1-((2 * CT(tr))**.5 / b(tr))

Vi(tr hover)=(T(tr) / (2 * rho * A(tr))**.5

Vi(tr fwd)= (-(v(fwd)**2 / 2) + (V(fwd)**2 / 2)**2
            *(Pi(fwd) / P(hover)**2 * Vi(tr hover)**4)**.5

Pi (tr fwd)= (1 / B(tr)) * T(tr) * Vi(tr fwd)

Pt(tr fwd)=Pi(tr fwd tl) + Po(tr fwd)

Mach Tip(tr)= (V(fwd) + V(tr tip)) /
              (gamma * g * R * T)**.5
```

where:

Pp is the parasite power.

EFPA (ff) is the effective flat plate area (forward flight).

Vi(hover) is the induced velocity in hover.

Pi(hover) is the induced power required to hover.

Po(hover) is the profile power required to hover.

SIGMA is the solidity.

Cdo is the coefficient of drag.

RHO is the density.

A(mr) is the area of the main rotor.

V(mr tip) is the tip velocity of the main rotor.

R(tr) is the radius of the tail rotor.

L(tr) is the length of the helicopter tail from the main rotor shaft to the tail rotor.

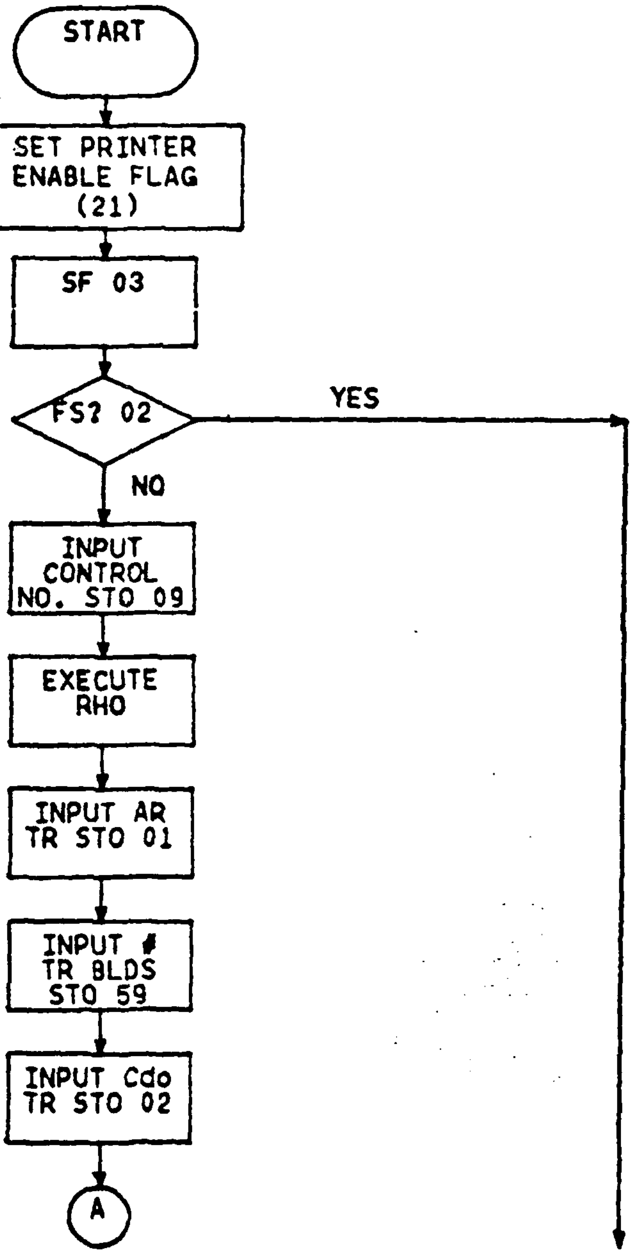
T(tr) is the thrust of the tail rotor.

CT(tr) is the coefficient of thrust of the tail rotor.

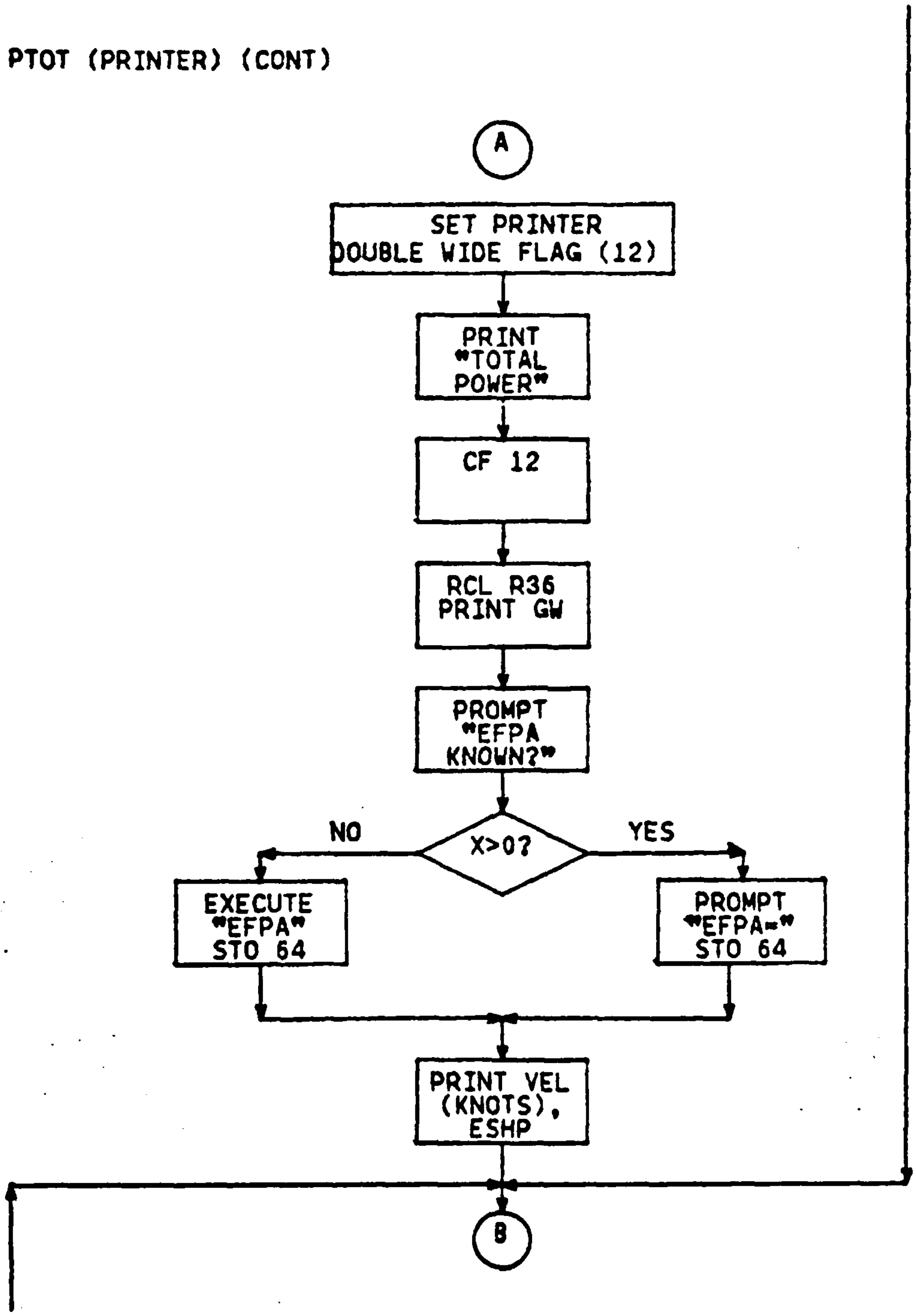
B(tr) is the tip loss (tl) factor (tail rotor).

3. FLOWCHART

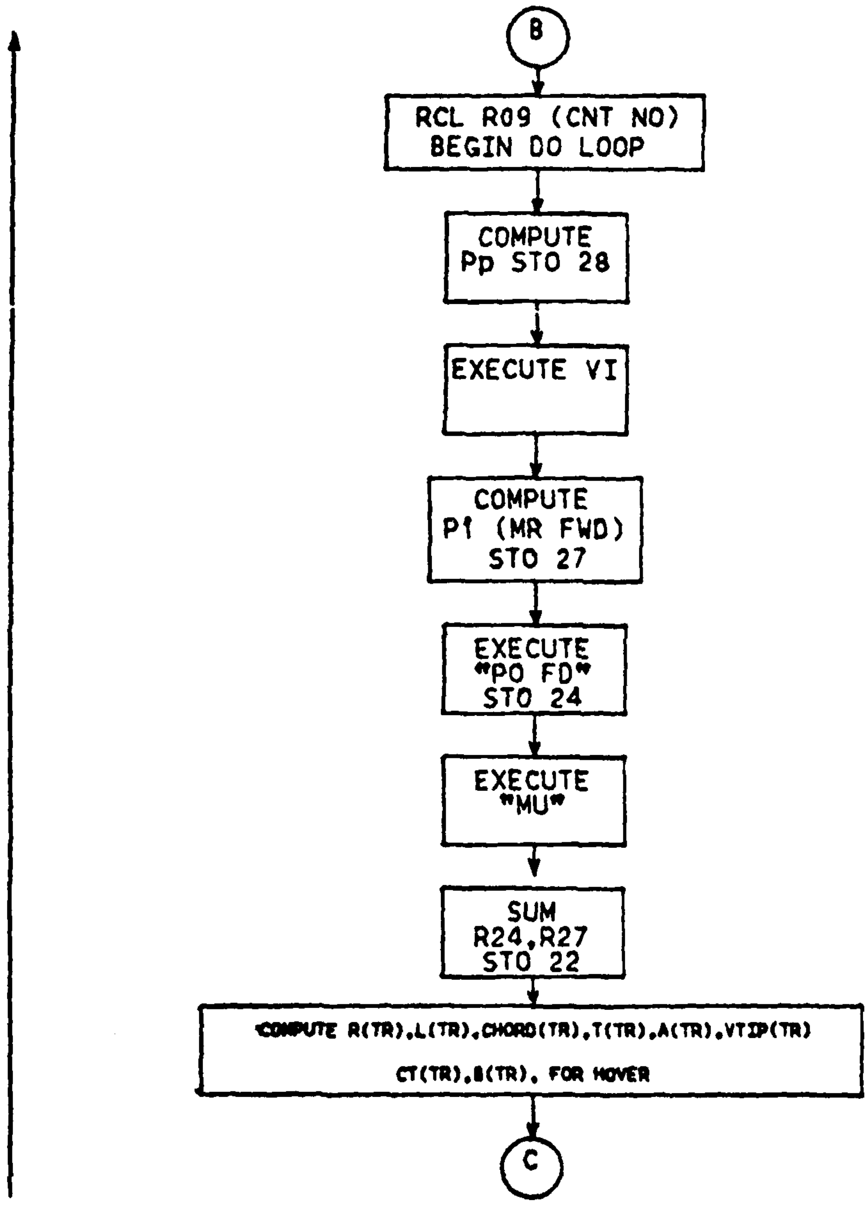
A. PTOT (PRINTER)



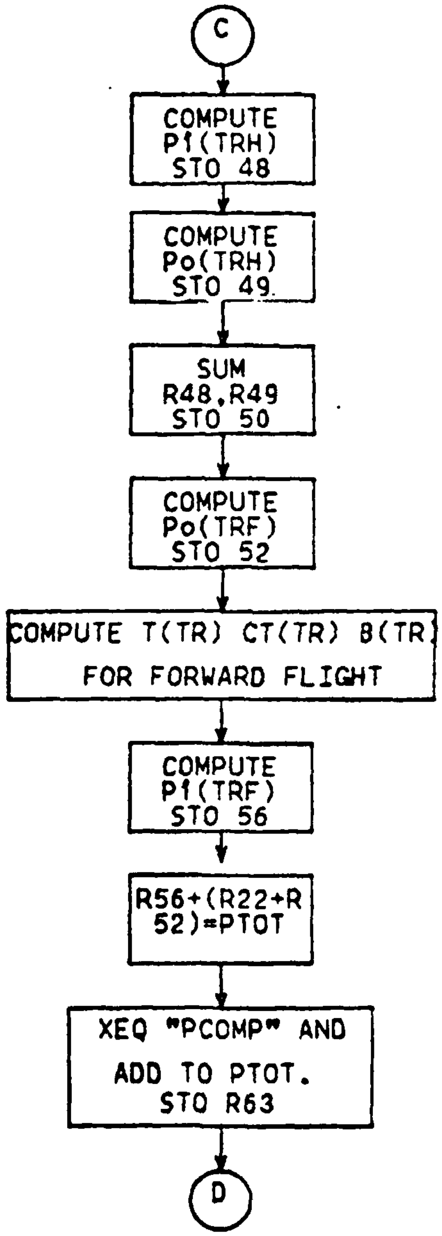
PTOT (PRINTER) (CONT)



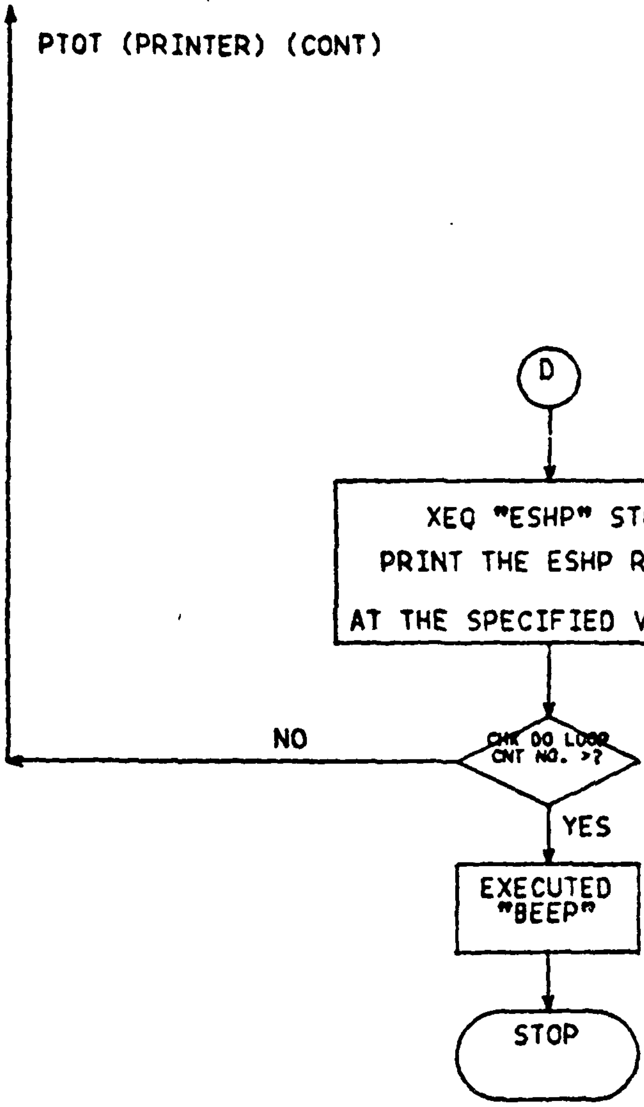
PTOT (PRINTER) (CONT)



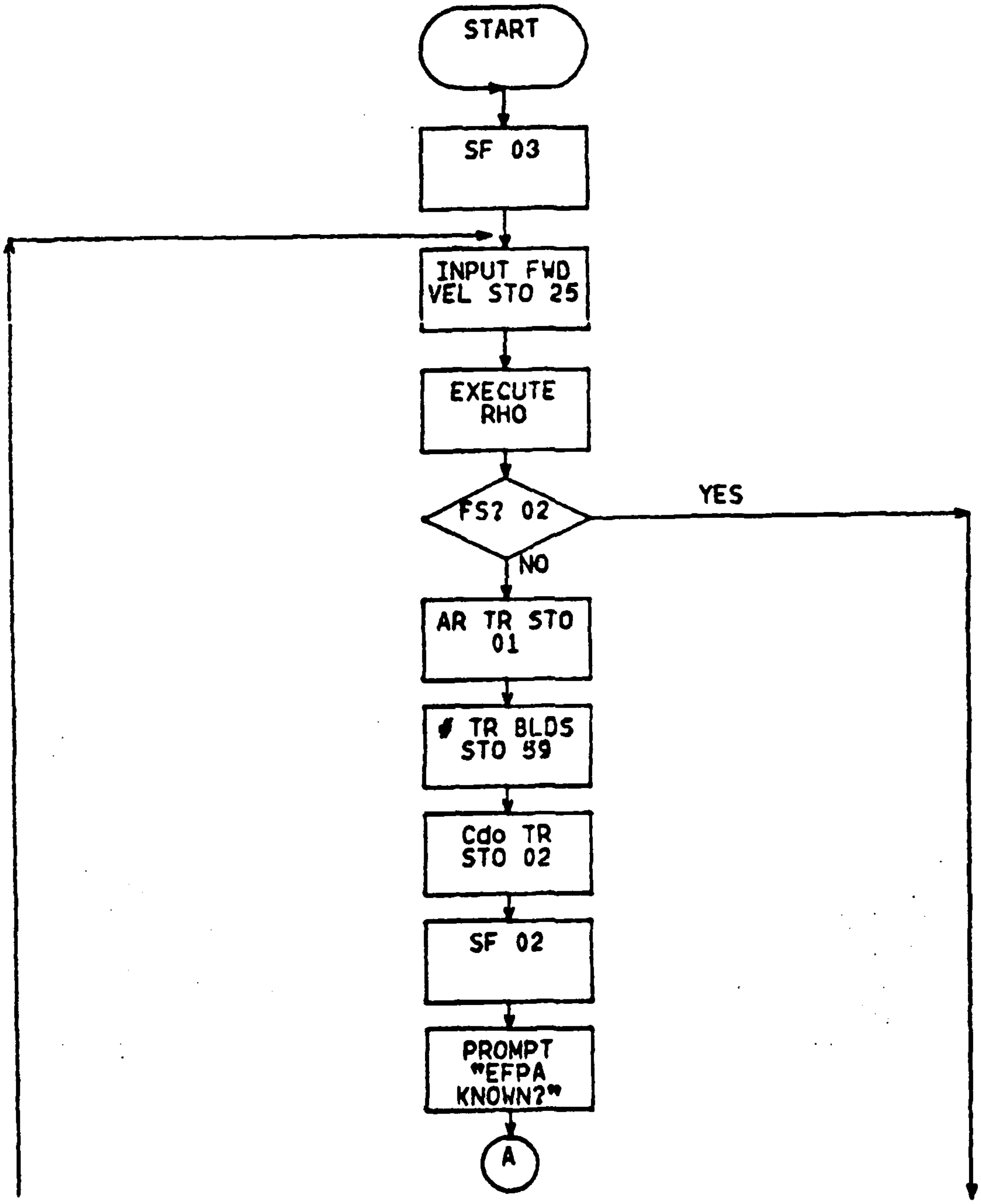
PTOT (PRINTER) (CONT)



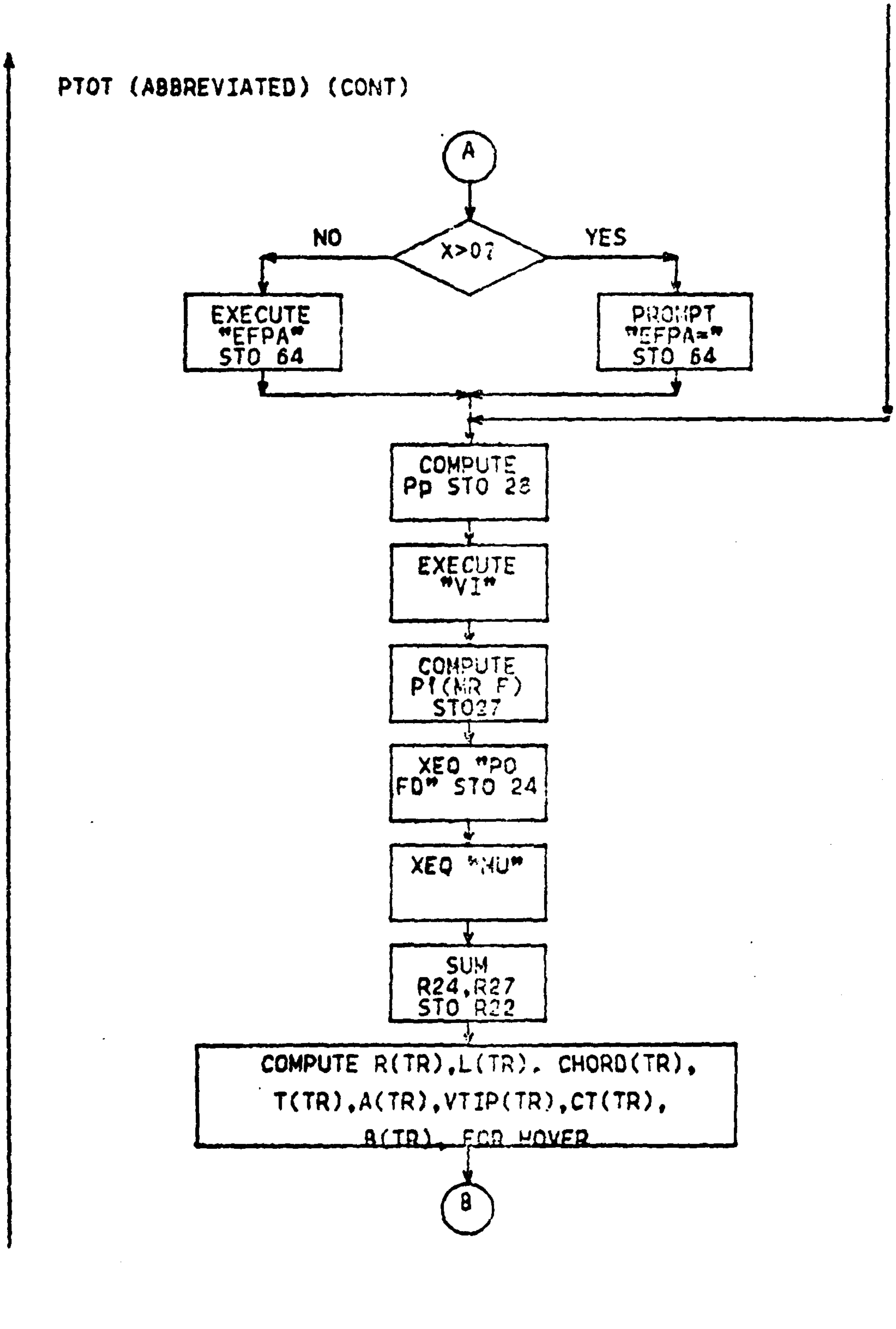
PTOT (PRINTER) (CONT)



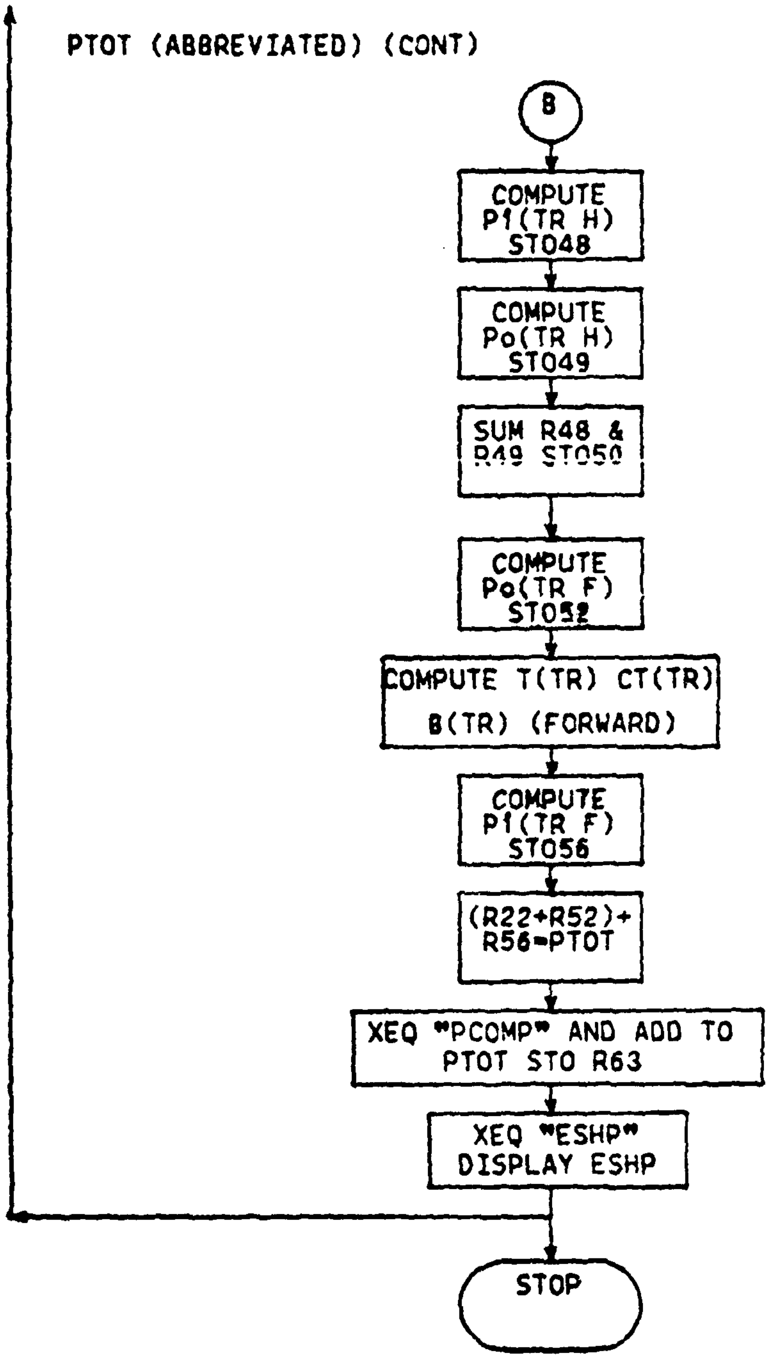
8. PTOT (ABBREVIATED)



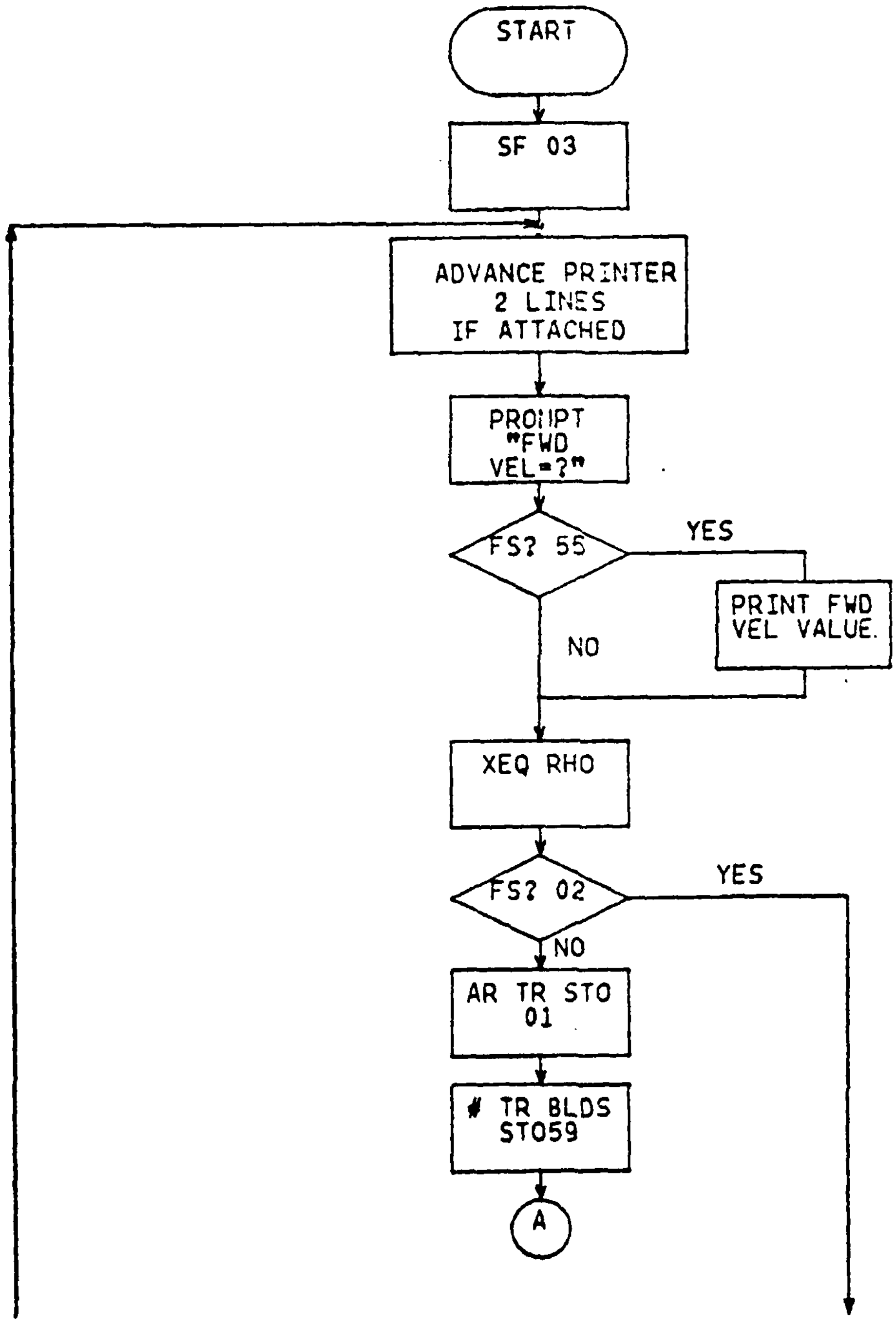
PTOT (ABBREVIATED) (CONT)



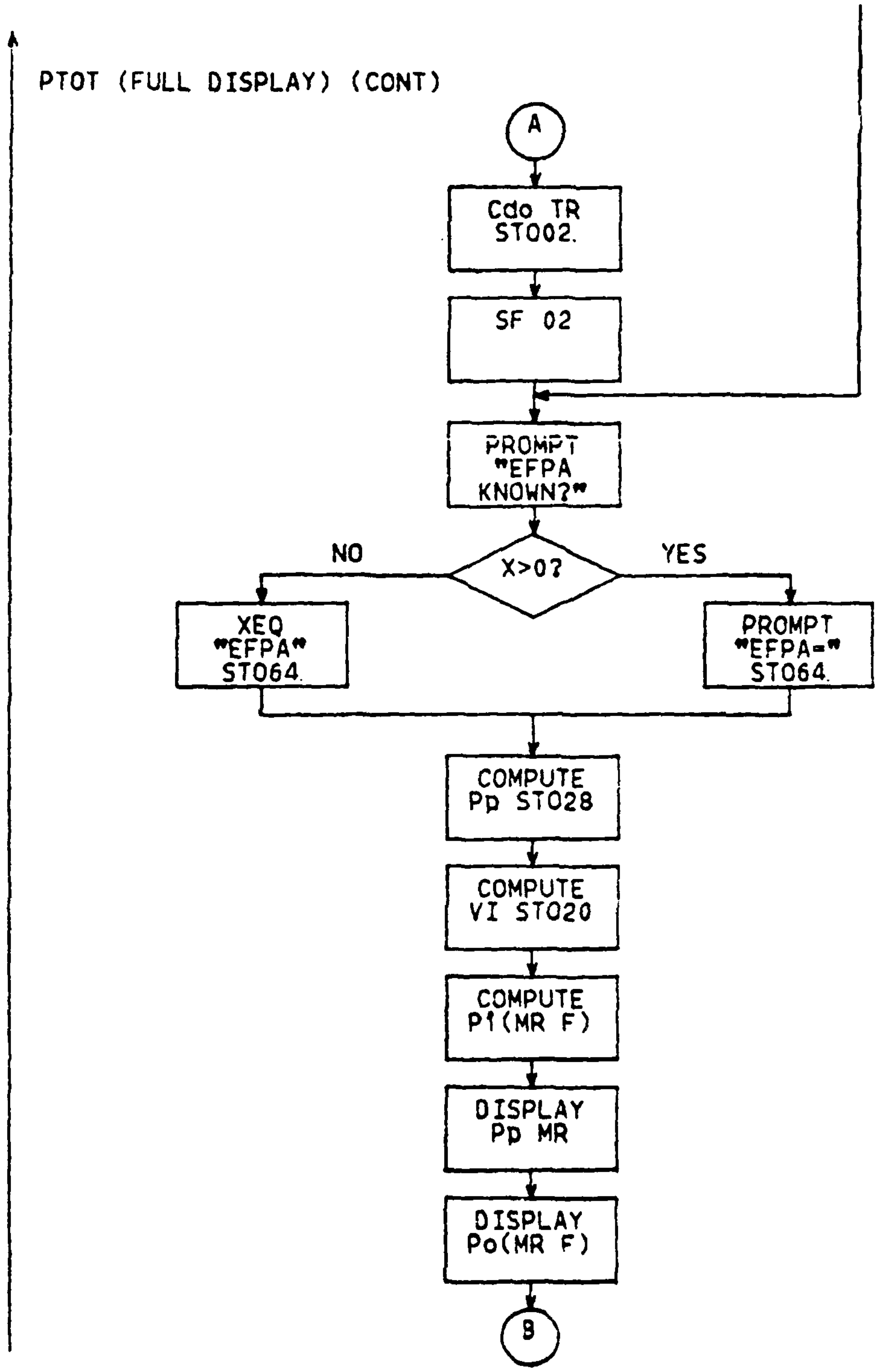
PTOT (ABBREVIATED) (CONT)



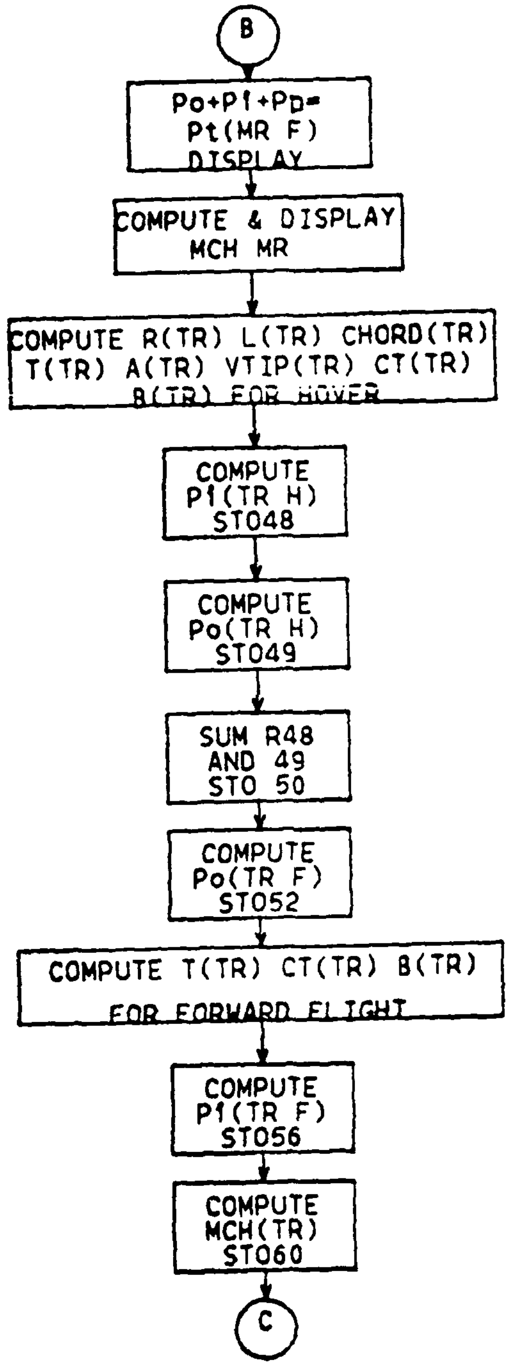
C. PTOT (FULL DISPLAY)



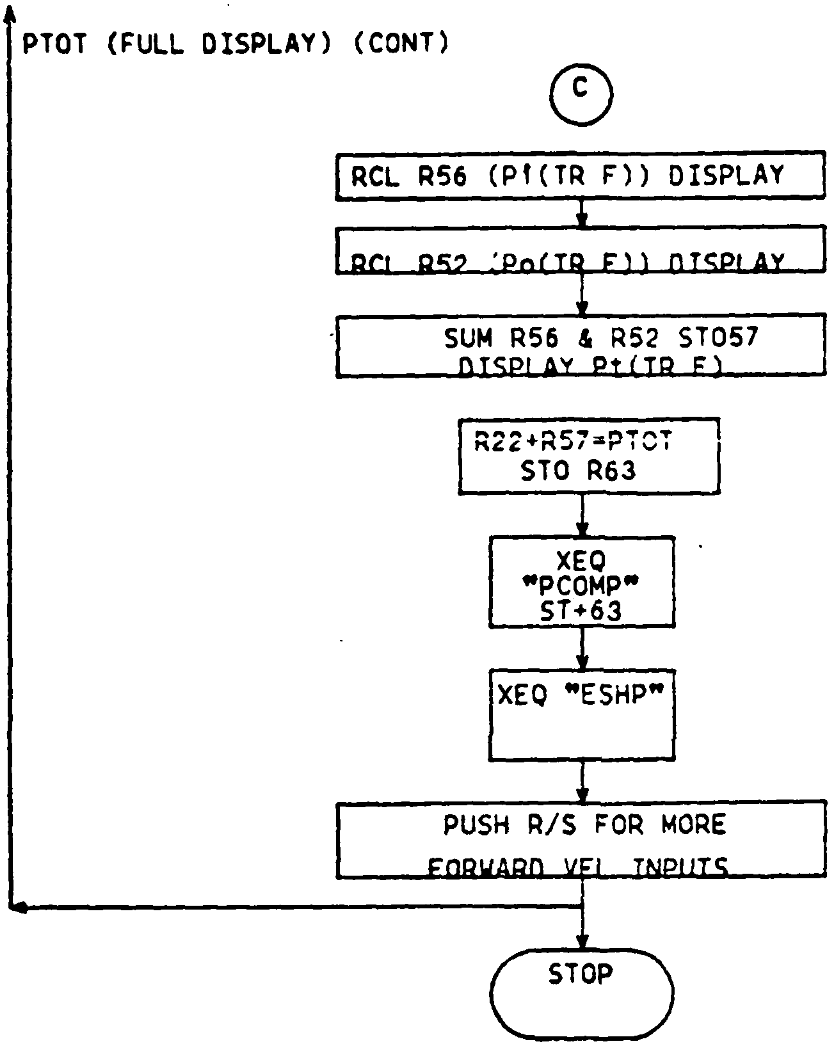
PTOT (FULL DISPLAY) (CONT)



PTOT (FULL DISPLAY) (CONT)



PTOT (FULL DISPLAY) (CONT)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS (PTOT--PRINTER)

Calculate the total engine shaft horsepower required for the example helicopter from 0 to 160 knots at standard sea level (0 PA, 15 DEG CEN). Increment the velocity every 20 knots.

Note: When prompted to input the control number, the user should recall that this number is of the form CCC.XXXFF. The CCC describes the starting value. .XXX is the final value, and FF is the incremental spacing. If the starting value is zero, the CCC need not be entered. For this example, input .16020.

KEYSTROKES		DISPLAY
XEQ (ALPHA) PTOT (ALPHA)		INPUT CNT NO.
0.16020	(R/S)	PA=?
0	(R/S)	TEMP C=?
15	(R/S)	AR TR=?
8	(R/S)	NO. TR BLS?
4	(R/S)	CDO TR=?
0.0145	(R/S)	EFPA KNOWN?
0	(R/S)	CLEAN LINES?
1	(R/S)	SKID?
1	(R/S)	EFPA=20.95
	(R/S)	NO. ENGS=?
2	(R/S)	

Note: This program can, at this point, only be executed using skid data because the gross weight computation used in the "WT" program was computed on the basis of skid landing gear.

Definitions:

PA is the pressure altitude.

TEMP C is the temperature in centigrade.

AR TR is the aspect ratio of the tail rotor (historically between 4.5 and 8.0).

NO. ENGS is the number of engines.

5. PRINTER OUTPUT

TOTAL POWER

GW=16744.99
EFPA=20.95

VEL (KNOTS)
ESHP

```
     0   ***
  1861   ***

    20   ***
  1608   ***

    40   ***
  1204   ***

    60   ***
  1107   ***

    80   ***
  1173   ***

   100   ***
  1356   ***

   120   ***
  1647   ***

   140   ***
  2049   ***

   160   ***
  2576   ***
```

6. EXAMPLE PROBLEM AND USER INSTRUCTIONS (PTOT--ABBREVIATED)

Note: Clear PTOT (PRINTER) and insert PTOT (ABBREVIATION).
Clear flags 02 and 05 manually.

KEYSTROKES	DISPLAY
(SHIFT) CF 02	0
(SHIFT) CF 05	0
XEQ (ALPHA) CLP (ALPHA)	CLP__
(ALPHA) PTOT (ALPHA)	-----

AFTER INPUTTING PTOT (ABBREVIATED):

KEYSTROKES		DISPLAY
XEQ (ALPHA) PTOT (ALPHA)		FWD VEL=?
0	(R/S)	PA=?
0	(R/S)	TEMP C=?
15	(R/S)	AR TR=?
8	(R/S)	NO. TR BLS?
4	(R/S)	CDO TR=?
0.0145	(R/S)	EFPA KNOWN?
1	(R/S)	EFPA=?
20.95	(R/S)	NO. ENGS=?
2	(R/S)	ESHP=1861.14
	(R/S)	FWD VEL?
20	(R/S)	ESHP=1608.01
	(R/S)	FWD VEL?
40	(R/S)	ESHP=1204.25
	(R/S)	FWD VEL?

60	(R/S)	1107.36
	(R/S)	FWD VEL?
80	(R/S)	1173.43
	(R/S)	FWD VEL?
100	(R/S)	ESHP=1356.32
	(R/S)	FWD VEL?
120	(R/S)	1646.68
	(R/S)	FWD VEL?
140	(R/S)	ESHP=2049.57
	(R/S)	FWD VEL?
160	(R/S)	ESHP=2575.93

Note: When prompted "EFPA KNOWN?" a 1 was inputted (Yes) since the EFPA was known from the PTOT (PRINTER) program. This results in a more rapid program execution.

7. EXAMPLE PROBLEM AND USER INSTRUCTIONS (PTOT-FULL DISPLAY)

Note: Clear PTOT (ABBREVIATION) and input PTOT (FULL DISPLAY). Also clear flags 02, 03, and 05.

KEYSTROKES		DISPLAY
XEQ (ALPHA) PTOT (ALPHA)		FWD VEL=?
0	(R/S)	PA=?
0	(R/S)	TEMP C=?
15	(R/S)	AR TR=?
8	(R/S)	NO. TR BLDS?
4	(R/S)	CDO TR=?
0.0145	(R/S)	EFPA KNOWN?

1 (R/S) EFPA=?

20.95 (R/S)

For the inputted forward velocity of 0 knots, the following power values are displayed:

Pi(fwd)=1227.14

Pp=0.0

Po(fwd)=296.54

Pt(fwd)=1523.69

MCH(mr)=.65

MCH(tr)=0.58

Pi(tr fwd)=85.04

Po(tr fwd)=29.51

Pt(tr fwd)=114.55

PTOT=1638.24

The user is then prompted for the number of engines (this only occurs during the first iteration). After inputting 2 engines, the engine shaft horsepower required at zero airspeed is displayed: 1861.14. After pushing the (r/s) key, the user will be prompted for the forward velocity, pressure altitude, and temperature. In this way, power requirements at any airspeed and altitude may be computed anytime during the program operation. The user may transcribe a table of values from the displayed output.

8. PRINTER OUTPUT (PTOT--FULL DISPLAY)

With the HP 82143A printer attached, the following data is outputted during the running of the program (two iterations are shown).

```
              0.00    ***
PI FD=1227.14
PP=0.00
PO FD=296.54
PT FD=1523.69
MCH MR=0.65
MCH TR=0.58
PI TRF=85.04
PO TRF=29.51
PT TRF=114.55
PTOT=1638.24
ESHP=1861.14

             20.00    ***
PI FD=1023.74
PP=1.74
PO FD=299.30
PT FD=1324.78
MCH MR=0.68
MCH TR=0.61
PI TRF=59.56
PO TRF=29.86
PT TRF=89.42
PTOT=1414.20
ESHP=1608.01
```

9. PROGRAM LISTINGS

A. PTOT (PRINTER) LISTING

```
01♦LBL "PTOT"
02 SF 21
03 SF 03
04 "INPUT CNT NO."
05 PROMPT
06 STO 09
07 FS? 02
08 GTO 02
09 XEQ "RHO"
10 "AR TR=?"
11 PROMPT
12 STO 01
13 "NO.TR BLS?"
14 PROMPT
15 STO 59
16 "CdO TR=?"
17 PROMPT
18 STO 02
19 SF 02
20♦LBL 02
21 SF 12
22 ADV
23 ADV
24 "TOTAL POWER"
25 PRA
26 ADV
27 ADV
28 CF 12
29 RCL 36
30 "GW="
31 ARCL X
32 AVIEW
33 "EFPA KNOWN?"
34 PROMPT
35 X≠0?
36 GTO 02
37 XEQ "EFPA"
38♦LBL "DD"
39 GTO 03
40♦LBL 02
41 "EFPA=?"
42 PROMPT
43 PRA
44 STO 64
45 XEQ "PRX"
46♦LBL 03
47 FIX 0
48 RCL 09
49 ADV
50 "VEL (KNOTS)"
51 PRA
52 "ESHP"
53 PRA
54 ADV
55♦LBL 01
56 RCL 09
57 INT
58 PRX
59 .59248
60 /
61 STO 25
62 3
63 Y↑X
64 RCL 64
65 RCL 11
66 *
67 .5
68 *
69 RCL 25
70 3
71 Y↑X
72 *
73 550
74 /
75 STO 28
76 GTO "PT FD"
77♦LBL "PO FD"
78 RCL 13
79 3
80 Y↑Y
81 RCL 12
82 *
83 RCL 11
84 *
85 RCL 07
86 *
87 RCL 19
88 *
89 4400
90 /
91 STO 21
92 XEQ "MU"
93 Y↑2
94 4.3
95 *
96 1
97 +
98 *
99 STO 24
100 RTN
101♦LBL "MU"
102 RCL 25
103 RCL 13
104 /
105 RTN
106♦LBL "VI"
107 RCL 36
108 RCL 11
109 RCL 12
110 *
111 2
112 *
113 /
114 SQRT
```

```
115 STO 20
116♦LBL "PI FD"
117 RCL 25
118 X↑2
119 RCL 20
120 X↑2
121 /
122 2
123 /
124 CHS
125 RCL 25
126 X↑2
127 RCL 20
128 X↑2
129 2
130 *
131 /
132 X↑2
133 1
134 +
135 SQRT
136 +
137 SQRT
138 RCL 20
139 *
140 RCL 36
141 *
142 RCL 15
143 /
144 550
145 /
146 STO 27
147 RTN
148♦LBL "PT FD"
149 XEQ "VI"
150 RCL 28
151 +
152 XEQ "PO FD"
153 +
154 STO 22
155♦LBL "TR"
156 RCL 36
157 1000
158 /
159 SQRT
160 1.3
161 *
162 STO 42
163 RCL 05
164 +
165 .5
166 +
167 STO 40
168 RCL 42
169 RCL 01
170 /
171 STO 58
172 RCL 30
173 550
174 *
175 RCL 08
176 RCL 40
177 *
178 /
179 STO 41
180 RCL 42
181 X↑2
182 PI
183 *
184 STO 43
185 4.5
186 ENTER↑
187 RCL 08
188 *
189 RCL 42
190 *
191 STO 44
192 X↑2
193 RCL 11
194 *
195 RCL 43
196 *
197 RCL 41
198 X<>Y
199 /
200 STO 45
201 2
202 *
203 SQRT
204 RCL 59
205 /
206 CHS
207 1
208 +
209 STO 47
210 RCL 41
211 1.5
212 Y↑X
213 RCL 43
214 RCL 11
215 *
216 2
217 *
218 SQRT
219 /
220 RCL 47
221 /
222 550
223 /
224 STO 48
225 RCL 59
226 RCL 58
227 *
228 RCL 42
```

```
229 PI
230 *
231 /
232 STO 29
233 RCL 44
234 3
235 Y↑X
236 RCL 43
237 *
238 RCL 11
239 *
240 RCL 02
241 *
242 RCL 29
243 *
244 4400
245 /
246 STO 49
247 RCL 48
248 +
249 STO 50
250◆LBL "TR2"
251 RCL 25
252 RCL 44
253 /
254 STO 51
255 X↑2
256 4.3
257 *
258 1
259 +
260 RCL 49
261 *
262 STO 52
263 RCL 22
264 RCL 08
265 RCL 40
266 *
267 /
268 550
269 *
270 STO 53
271 RCL 43
272 RCL 11
273 *
274 RCL 44
275 X↑2
276 *
277 /
278 STO 54
279 2
280 *
281 SQRT
282 RCL 59
283 /
284 CHS
285 1
286 +
287 STO 55
288 RCL 25
289 X↑2
290◆LBL "VI(TR)"
291 RCL 53
292 RCL 11
293 RCL 43
294 *
295 2
296 *
297 /
298 SQRT
299 STO 26
300 X↑2
301 /
302 2
303 /
304 CHS
305 RCL 25
306 X↑2
307 RCL 26
308 X↑2
309 2
310 *
311 /
312 X↑2
313 1
314 +
315 SQRT
316 +
317 SQRT
318 RCL 26
319 *
320 RCL 53
321 *
322 550
323 /
324 RCL 55
325 /
326 STO 56
327 RCL 22
328 +
329 RCL 52
330 +
331 XEQ "PCOMP"
332 +
333 STO 63
334 XEQ "ESHP"
335 STO 63
336 PRX
337 ADV
338 ISG 09
339 GTO 01
340 BEEP
341 STOP
342 END
```

B. PTOT (ABBREVIATED) LISTING

```
01♦LBL "PTOT"
02 SF 03
03♦LBL 03
04 FIX 2
05 "FWD VEL?"
06 PROMPT
07 .59248
08 /
09 STO 25
10 3
11 Y↑X
12 FS? 05
13 GTO 04
14 XEQ "RHO"
15 FS? 02
16 GTO 04
17 "AR TR=?"
18 PROMPT
19 STO 01
20 "NO.TR BLS?"
21 PROMPT
22 STO 59
23 "Cd0 TR=?"
24 PROMPT
25 STO 02
26 SF 02
27 "EFPA KNOWN?"
28 PROMPT
29 X>0?
30 GTO 02
31 XEQ "EFPA"
32♦LBL "DD"
33 GTO 04
34♦LBL 02
35 "EFPA=?"
36 PROMPT
37 STO 64
38♦LBL 04
39 RCL 64
40 RCL 11
41 *
42 .5
43 *
44 RCL 25
45 3
46 Y↑X
47 *
48 550
49 /
50 STO 26
51 GTO "PT FD"
52♦LBL "PO FD"
53 RCL 13
54 3
55 Y↑X
56 RCL 12
57 *
58 RCL 11
59 *
60 RCL 07
61 *
62 RCL 19
63 *
64 4400
65 /
66 STO 21
67 XEQ "MU"
68 X↑2
69 4.3
70 *
71 1
72 +
73 *
74 STO 24
75 RTN
76♦LBL "MU"
77 RCL 25
78 RCL 13
79 /
80 RTN
81♦LBL "VI"
82 RCL 36
83 RCL 11
84 RCL 12
85 *
86 2
87 *
88 /
89 SQRT
90 STO 20
91♦LBL "PI FD"
92 RCL 25
93 X↑2
94 RCL 20
95 X↑2
96 /
97 2
98 /
99 CHS
100 RCL 25
101 X↑2
102 RCL 20
103 X↑2
104 2
105 *
106 /
107 X↑2
108 1
```

```
109 +
110 SQRT
111 +
112 SQRT
113 RCL 20
114 *
115 RCL 36
116 *
117 RCL 15
118 /
119 550
120 /
121 STO 27
122 RTN
123◆LBL "PT FD"
124 XEQ "VI"
125 RCL 28
126 +
127 XEQ "PO FD"
128 +
129 STO 22
130◆LBL "TR"
131 FIX 2
132 RCL 36
133 1000
134 /
135 SQRT
136 1.3
137 *
138 STO 42
139 RCL 05
140 +
141 .5
142 +
143 STO 40
144 RCL 42
145 RCL 01
146 /
147 STO 58
148 RCL 30
149 550
150 *
151 RCL 08
152 RCL 40
153 *
154 /
155 STO 41
156 RCL 42
157 X↑2
158 PI
159 *
160 STO 43
161 4.5
162 ENTER↑
163 RCL 08
164 *
165 RCL 42
166 *
167 STO 44
168 X↑2
169 RCL 11
170 *
171 RCL 43
172 *
173 RCL 41
174 X<>Y
175 /
176 STO 45
177 2
178 *
179 SQRT
180 RCL 59
181 /
182 CHS
183 1
184 +
185 STO 47
186 RCL 41
187 1.5
188 Y↑X
189 RCL 43
190 RCL 11
191 *
192 2
193 *
194 SQRT
195 /
196 RCL 47
197 /
198 550
199 /
200 STO 48
201 RCL 59
202 RCL 58
203 *
204 RCL 42
205 PI
206 *
207 /
208 STO 29
209 RCL 44
210 3
211 Y↑X
212 RCL 43
213 *
214 RCL 11
215 *
216 RCL 02
```

```
*
RCL 29
*
4400
/
STO 49
RCL 48
+
STO 50
♦LBL "TR2"
RCL 25
RCL 44
/
STO 51
X↑2
4.3
*
1
+
RCL 49
*
STO 52
RCL 22
RCL 08
RCL 40
*
/
550
*
STO 53
RCL 43
RCL 11
*
RCL 44
X↑2
*
/
STO 54
2
*
SQRT
RCL 59
/
CHS
1
+
STO 55
RCL 25
X↑2
♦LBL "VI(TR)"
RCL 53
RCL 11
RCL 43
*
2
*
/
SQRT
STO 26
X↑2
/
2
/
CHS
RCL 25
X↑2
RCL 26
X↑2
2
*
/
X↑2
1
+
SQRT
+
SQRT
RCL 26
*
RCL 53
*
550
/
RCL 55
/
STO 56
RCL 22
+
RCL 52
+
XEQ "PCOMP"
+
STO 63
XEQ "ESHP"
STO 63
"ESHP="
ARCL X
AVIEW
STOP
GTO 03
END
```

C. PTOT (FULL DISPLAY) LISTING

```
01♦LBL "PTOT"
02 SF 03
03♦LBL 03
04 FIX 2
05 ADV
06 ADV
07 "FWD VEL=?"
08 PROMPT
09 FS? 55
10 PRX
11 .59248
12 /
13 STO 25
14 3
15 Y↑X
16 XEQ "RHO"
17 FS? 02
18 GTO 04
19 "AP TR=?"
20 PROMPT
21 STO 01
22 "NO. TR BLDS?"
23 PROMPT
24 STO 59
25 "Cd0 TR=?"
26 PROMPT
27 STO 02
28 SF 02
29 "EFPA KNOWN?"
30 PROMPT
31 X>0?
32 GTO 02
33 XEQ "EFPA"
34♦LBL "DD"
35 GTO 04
36♦LBL 02
37 "EFPA=?"
38 PROMPT
39 STO 64
40♦LBL 04
41 RCL 64
42 RCL 11
43 *
44 .5
45 *
46 RCL 25
47 3
48 Y↑X
49 *
50 550
51 /
52 STO 28
53 GTO "PT FD"
54♦LBL "PO FD"
55 RCL 13
56 3
57 Y↑X
58 RCL 12
59 *
60 RCL 11
61 *
62 RCL 07
63 *
64 RCL 19
65 *
66 4400
67 /
68 STO 21
69 XEQ "MU"
70 X↑2
71 4.3
72 *
73 1
74 +
75 *
76 STO 24
77 "PO FD="
78 ARCL X
79 AVIEW
80 STOP
81 RTN
82♦LBL "MU"
83 RCL 25
84 RCL 13
85 /
86 RTN
87♦LBL "VI"
88 RCL 36
89 RCL 11
90 RCL 12
91 *
92 2
93 *
94 /
95 SQRT
96 STO 20
97♦LBL "PI FD"
98 RCL 25
99 X↑2
100 RCL 20
101 X↑2
102 /
103 2
104 /
105 CHS
106 RCL 25
107 X↑2
108 RCL 20
109 X↑2
110 2
111 *
112 /
113 X↑2
114 1
115 +
116 SQRT
117 +
118 SQRT
119 RCL 20
120 *
121 RCL 36
122 *
123 RCL 15
124 /
125 550
126 /
127 STO 27
128 RTN
129♦LBL "PT FD"
```

```
130 XEQ "VI"
131 "PI FD="
132 ARCL X
133 AVIEW
134 STOP
135 RCL 28
136 "PP="
137 ARCL X
138 AVIEW
139 STOP
140 +
141 XEQ "PO FD"
142 +
143 "PT FD="
144 ARCL X
145 AVIEW
146 STO 22
147 STOP
148 RCL 25
149 RCL 13
150 +
151 401.8
152 ENTER↑
153 RCL 18
154 *
155 SQRT
156 .3048
157 /
158 /
159 "MCH NR="
160 ARCL X
161 AVIEW
162 STO 37
163 STOP
164♦LBL "TR"
165 FIX 2
166 RCL 36
167 1000
168 /
169 SQRT
170 1.3
171 *
172 STO 42
173 RCL 05
174 +
175 .5
176 +
177 STO 40
178 RCL 42
179 RCL 01
180 /
181 STO 58
182 RCL 30
183 550
184 *
185 RCL 08
186 RCL 40
187 *
188 /
189 STO 41
190 RCL 42
191 X↑2
192 PI
193 *
194 STO 43
195 4.5
196 ENTER↑
197 RCL 08
198 *
199 RCL 42
200 *
201 STO 44
202 X↑2
203 RCL 11
204 *
205 RCL 43
206 *
207 RCL 41
208 X<>Y
209 /
210 STO 45
211 2
212 *
213 SQRT
214 RCL 59
215 /
216 CHS
217 1
218 +
219 STO 47
220 RCL 41
221 1.5
222 Y↑X
223 RCL 43
224 RCL 11
225 *
226 2
227 *
228 SQRT
229 /
230 RCL 47
231 /
232 550
233 /
234 STO 48
235 RCL 59
236 RCL 58
237 *
238 RCL 42
239 PI
240 *
241 /
242 STO 29
243 RCL 44
244 3
245 Y↑X
246 RCL 43
247 *
248 RCL 11
249 *
250 RCL 02
251 *
252 RCL 29
253 *
254 4400
255 /
256 STO 49
257 RCL 48
258 +
```

```
259 STO 50
260♦LBL "TP2"
261 RCL 25
262 RCL 44
263 /
264 STO 51
265 X↑2
266 4.3
267 *
268 1
269 +
270 RCL 49
271 *
272 STO 52
273 RCL 22
274 RCL 08
275 RCL 40
276 *
277 /
278 550
279 *
280 STO 53
281 RCL 43
282 RCL 11
283 *
284 RCL 44
285 X↑2
286 *
287 /
288 STO 54
289 2
290 *
291 SQRT
292 RCL 59
293 /
294 CHS
295 1
296 +
297 STO 55
298 RCL 25
299 X↑2
300♦LBL "VI(TR)"
301 RCL 53
302 RCL 11
303 RCL 43
304 *
305 2
306 *
307 /
308 SQRT
309 STO 26
310 X↑2
311 /
312 2
313 /
314 CHS
315 RCL 25
316 X↑2
317 RCL 26
318 X↑2
319 2
320 *
321 /
322 X↑2
323 1
324 +
325 SQRT
326 +
327 SQRT
328 RCL 26
329 *
330 RCL 53
331 *
332 550
333 /
334 RCL 55
335 /
336 STO 56
337 RCL 52
338 +
339 STO 57
340 RCL 25
341 RCL 44
342 +
343 RCL 18
344 401.8
345 *
346 SQRT
347 .3048
348 /
349 /
350 STO 60
351 "MCH TR="
352 ARCL X
353 AVIEW
354 STOP
355 RCL 56
356 "PI TRF="
357 ARCL X
358 AVIEW
359 STOP
360 RCL 52
361 "PO TRF="
362 ARCL X
363 AVIEW
364 STOP
365 RCL 57
366 "PT TRF="
367 ARCL X
368 AVIEW
369 STOP
370 RCL 22
371 +
372 "PTOT="
373 ARCL X
374 AVIEW
375 STO 63
376 STOP
377 XEQ "PCOMP"
378 ST+ 63
379 XEQ "ESHP"
380 "ESHP="
381 ARCL X
382 AVIEW
383 STOP
384 GTO 03
385 END
```

PCOMP (POWER REQUIRED DUE TO COMPRESSIBILITY EFFECTS)

1. PURPOSE

This subroutine is used in the main program, PTOT. It computes the additional horsepower necessary due to the compressibility effects from the main rotor.

2. EQUATIONS

```
M(tip mr)= (V(tip mr) + V(fwd mr)) /
           (gamma * g * R * T)**.5

MD= M(tip mr) - M(crit) - 0.06

P(COMP)= rho * A(mr) * V(tip mr)**3 * sigma(mr) *
         (0.012 * MD + 0.01 * MD**3)
```

where:

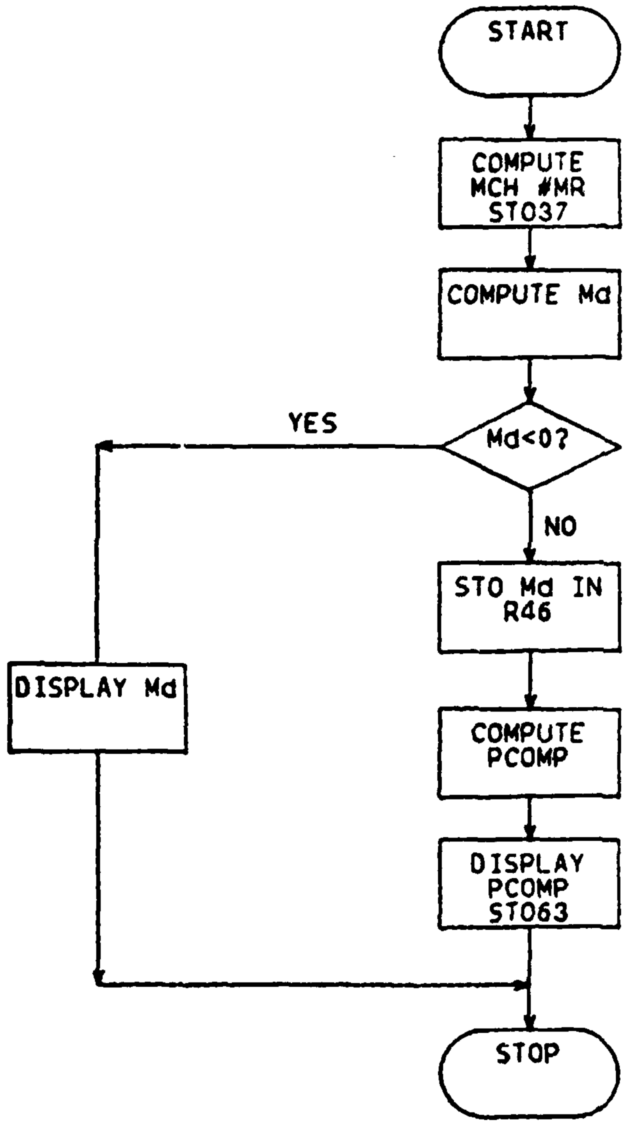
V(fwd) is the forward velocity in knots.

V(tip) is the main rotor tip velocity.

M(crit) is the critical mach number (a good approximation is .65).

DISCUSSION: The horsepower required due to compressibility effects does not become a positive value until a certain forward velocity is attained. By providing a check for negative MD, only positive values of PCOMP are stored in Register 63 (R63). When run independent of the main program, MD is displayed if the value is negative. PCOMP is displayed and stored in R63 otherwise. When run in conjunction with PTOT, MD and PCOMP are not displayed. PCOMP is computed and added to the total power computed in PTOT.

3. FLOWCHART (PCOMP)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS:

A) Compute the horsepower required due to compressibility effects at 20 knots forward velocity, 0 PA, and 15 deg C.

Register 25 contains the value, in ft per sec, of forward velocity. Register 11 contains the density altitude (rho). To execute PCOMP independent of the main program, the desired forward velocity must be converted to units of ft/sec and stored into Register 25. The subroutine "rho" must be executed to insure the correct value of density is stored in Register 11.

KEYSTROKES	DISPLAY
20 enter	20.00--
0.59248 /	33.76
sto 25	33.76
XEQ (alpha) RHO (alpha)	PA=?
0 (r/s)	TEMP C=?
15 (r/s)	2.38 -03
XEQ (alpha) PCOMP (alpha)	-0.03

DISCUSSION: At 20 knots, the compressibility factor is negative, therefore there is no extra horsepower needed due to compressibility effects. The value of MD is displayed.

B) Compute the horsepower required due to compressibility effects at 160 knots forward airspeed, 4000 ft pa, 35 deg C.

KEYSTROKES	DISPLAY
160 enter	160
0.59248 /	270.05
STO 25	270.05
XEQ (alpha) RHO (alpha)	PA=?
4000 (r/s)	TEMP C=?
35 (r/s)	1.92 -03
XEQ (alpha) PCOMP (alpha)	418.48

DISCUSSION: At a forward velocity of 160 knots at 4000 ft PA and 35 deg C, an additional power requirement of 418.48 horsepower results due to compressibility effects from the main rotor. This value is stored in Register 63 and will be added to other power requirements in the main program.

5. PROGRAM LISTING

```
01◆LBL "PCOMP"
02 RCL 25
03 RCL 13
04 +
05 RCL 18
06 401.8
07 *
08 SQRT
09 /
10 .3048
11 *
12 STO 37
13 RCL 03
14 -
15 .06
16 -
17 X<0?
18 GTO 01
19 STO 46
20 3
21 Y↑X
22 .1
23 *
24 .012
25 ENTER↑
26 RCL 46
27 *
28 +
29 RCL 19
30 *
31 RCL 13
32 3
33 Y↑X
34 *
35 RCL 12
36 *
37 RCL 11
38 *
39 550
40 /
41 STO 63
42◆LBL 01
43 END
```

ESHP (EQUIVALENT SHAFT HORSEPOWER)

1. PURPOSE

This subroutine is used in the main program PTOT. It computes the engine shaft horsepower required. The ESHP is equivalent to the rotor shaft horsepower (PTOT + PCOMP) adjusted for transmission and accessory losses. In addition, a 10 percent shaft horsepower loss is computed for every additional engine installed.

2. EQUATIONS

$$ESHP = (0.10 * RSHP * (N-1) + 1.03 * RSHP + 10.0\ HP$$

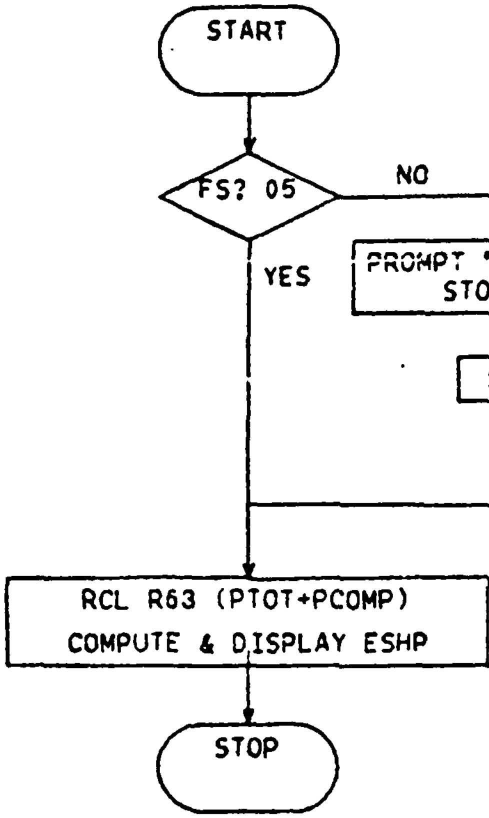
where:

N is the number of engines installed.

10.0 hp is the approximate horsepower required due to accessory usage.

RSHP is the rotor shaft horsepower (PTOT + PCOMP).

3. FLOWCHART (ESHP)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS

Compute the engine shaft horsepower required for a helicopter with two engines having a RSHP of 1500 hp.

KEYSTROKES	DISPLAY
1500 STO 63	1500
CF 05	1500
XEQ (alpha) ESHP (alpha)	NO. ENGS=?
2 (r/s)	1705.00

DISCUSSION: A helicopter with a RSHP of 1500 hp will require 205 additional horsepower due to transmission and accessory losses, as well as a 10 percent SHP loss due to an additional engine. To execute this subroutine independently of the main program, a value for RSHP must be known and stored in R63. Flag 05 must be cleared for the prompt "NO. ENGS=?" to be viewed.

5. PROGRAM LISTING

```
01♦LBL "ESHP"          12 RCL 63
02 FS? 05              13 *
03 GTO 01              14 .1
04 "NO. ENGS=?"        15 *
05 PROMPT              16 RCL 63
06 STO 67              17 1.03
07 SF 05               18 *
08♦LBL 01              19 +
09 RCL 67              20 10
10 1                   21 +
11 -                   22 END
```

FM (FIGURE OF MERIT)

1. PURPOSE

This subroutine is used in the main program PHV (Power to Hover). It computes the Figure of Merit which is the ratio of induced power (Pi), to the total power (Pt), of the main rotor. A computer value of between 0.7 and 0.8 is acceptable.

2. EQUATIONS

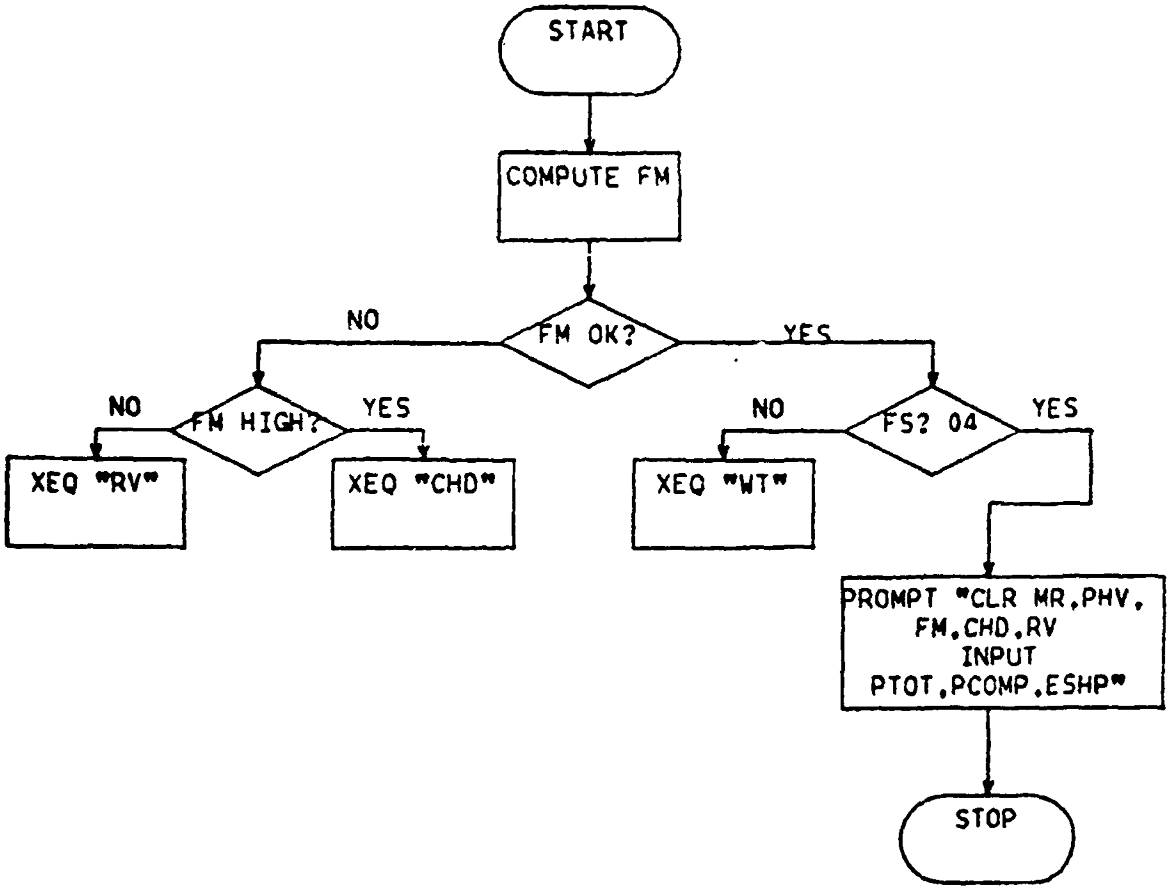
```
FM= (100 - ((Pt(mr ige) - Pi(mr oge)) / Pi(mr oge))
     * 100) * .01
```

where:

Pt(mr ige) is the total power required to hover in ground effect for the main rotor (stored in R30).

Pi(mr oge) is the induced power required out of ground effect for the main rotor (stored in R16).

3. FLOWCHART (FM)



4. EXAMPLE PROBLEM AND USER INSTRUCTIONS:

A) Compute the Figure of Merit of a helicopter which has Pi(mr oge) of 1000 hp and a Pt(mr ige) of 1500 hp.

KEYSTROKES		DISPLAY
1000 STO 16		1000
1500 STO 30		1500
XEQ (alpha) FM (alpha)		FIG MER=0.50
(r/s)		FM OK?
0	(r/s)	FM HIGH?
0	(r/s)	(program transfers to subroutine "RV")

B) Compute the Figure of Merit for a helicopter with a Pi(mr oge) of 1250 hp and a Pt(mr ige) of 1400 hp.

KEYSTROKES		DISPLAY
1250 STO 16		1250
1400 STO 30		1400
XEQ (alpha) FM (alpha)		FIG MER=0.88
	(r/s)	FM OK?
0	(r/s)	FM HIGH?
1	(r/s)	(program transfers to subroutine (CHD")

C) Compute the Figure of Merit for a helicopter with a Pi(mr oge) of 1200 hp and a Pt(mr ige) of 1500 hp.

KEYSTROKES	DISPLAY
1200 STO 16	1200
1500 STO 30	1500

	XEQ (alpha) FM (alpha)		FIG MER=0.75
	(r/s)		FM OK?
1	(r/s)	(If flag 04 is set, the user is prompted "clr MR, PHV, FM, CHD, RV, input PTOT, PCOMP, ESHP." If flag 04 is not set, the program transfers to the "WT" program and the first empty weight approximation is displayed.)	

DISCUSSION: To run this subroutine independently of the main program "PHV," the values for Pi(mr oge) and Pt(mr ige) must be inputted manually into their appropriate registers. In the first example, the Figure of Merit was computed to be 0.50, well below the minimum acceptable value of 0.70. The subroutine "RV" was therefore executed (this subroutine enables the user to increase the FM value). In the second example, the Figure of Merit was higher than the acceptable value of 0.80 and the subroutine "CHD" was executed (this subroutine enables the user to decrease the FM value). In the third example, the Figure of Merit was within the specified limits. When executing "FM" as part of the main program, if the "WT" program has not been executed (flag 04 has not been set), then the program automatically transfers to "WT" and displays the first approximation for the aircraft empty weight (.6 * spec. wt). If, however, flag 04 is set, the user is instructed to clear from program memory the programs that are no longer needed and to input three additional programs.

5. PROGRAM LISTING

```
01♦LBL "FM"
02 FIX 2
03 RCL 16
04 ENTER↑
05 RCL 30
06 %CH
07 100
08 X<>Y
09 -
10 .01
11 *
12 "FIG MEP="
13 ARCL X
14 AVIEW
15 FIX 4
16 STOP
17 "FM OK?"
18 PROMPT
19 X=0?
20 GTO 02
21 FS? 04
22 GTO 01
23 XEQ "WT"
24♦LBL 01
25 "CLR MP, PHV, FM"
26 "├, CHD, RV"
27 PROMPT
28 "├INPUT PTOT, PC"
29 "├OMP, ESHP,"
30 PROMPT
31 GTO 04
32♦LBL 02
33 "FM HIGH?"
34 PROMPT
35 X>0?
36 GTO 03
37 XEQ "RV"
38♦LBL 03
39 XEQ "CHD"
40♦LBL 04
41 END
```

CHD (CHORD)

1. PURPOSE

This subroutine is called up in the "FM" program. It is designed to reduce the value computed for the Figure of Merit. When executed, the former chord value is displayed momentarily. The user must input a larger value of chord length. This larger chord will increase the solidity, decrease the blade loading and decrease the aspect ratio. Once these values have been computed and stored in their appropriate registers, the program transfers to the "MR" program and immediately displays the values for DL, RV, CT, SD, c, AR, and CL. Program execution continues as before. A new Figure of Merit will be displayed. Proceed as before, depending on this value.

2. EQUATIONS

SD=(c * b) / (PI * R)

BL=CT / SD

AR=R / c

where:

SD is the solidity.

c is the chord.

b is the number of main rotor blades.

R is the radius of the main rotor.

CT is the coefficient of thrust (main rotor).

AR is the aspect ratio.

3. FLOWCHART (None)

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS:

This subroutine can only be used in conjunction with several main programs. See "PHV" for example problems involving this subroutine.

5. PROGRAM LISTING

```
01♦LBL "CH"
02 RCL 04
03 "CH="
04 ARCL X
05 AVIEW
06 PSE
07 "NEW CD=?"
08 PROMPT
09 STO 04
10 RCL 06
11 *
12 RCL 05
13 ENTER↑
14 PI
15 *
16 /
17 STO 19
18 RCL 14
19 X<>Y
20 /
21 "BL="
22 ARCL X
23 AVIEW
24 STOP
25 RCL 05
26 RCL 04
27 /
28 STO 32
29 GTO "AA"
30 END
```

RV (ROTATIONAL VELOCITY)

1. PURPOSE

This subroutine is called up in the "FM" program. It is designed to increase the computed Figure of Merit values. When executed, the former tip velocity is displayed momentarily. The user is then instructed to input a new value for V(tip). This value must be lower than the former value. The program then calculates new values for RV, BL, CT, SD, c, AR, and CL using the new V(tip). The program automatically transfers to "MR" and displays DL and the above values. Program execution continues as before. A new Figure of Merit will be displayed. Proceed as before, depending on the value. The user should be aware that a dramatic reduction in V(tip) is required to increase the Figure of Merit.

2. EQUATIONS

RV= V(tip) / R

BL= -0.16667 * ((V)max fwd) / 0.59248) / V(tip))
 + .15515

CT= GW / (A * rho * V(tip)**2)

SD= CT / BL

c= (SD * PI * R(mr)) / b(mr)

AR= R(mr) / c(mr)

CL= (6.0 * CT) / SD

where:

GW is the gross weight.

R(mr) is the radius of the main rotor.

V(tip) is the maximum tip velocity of the main rotor.

RV is the rotational velocity of the main rotor.

CT is the coefficient of thrust of the main rotor.

rho is the density.

SD is the solidity.

BL is the blade loading.

b is the number of main rotor blades.

c is the chord.

AR is the aspect ratio.

CL is the coefficient of lift.

3. FLOWCHART (None)

4. EXAMPLE PROBLEM AND USER INSTRUCTIONS:

This subroutine can only be used in conjunction with several main programs. See "PHV" for example problems involving this subroutine.

5. PROGRAM LISTING

```
♦LBL "RV"
RCL 13
"VTIP="
ARCL X
AVIEW
PSE
"NEW VTIP=?"
PROMPT
STO 13
RCL 05
/
STO 08
RCL 23
RCL 13
/
.166667
CHS
*
.15515
+
"BL="
ARCL X
AVIEW
STOP
RCL 12
RCL 11
*
RCL 13
X↑2
*
RCL 36
X<>Y
/
STO 14
X<>Y
/
STO 19
PI
*
RCL 05
*
RCL 06
/
STO 04
RCL 05
X<>Y
/
STO 32
RCL 14
6
*
RCL 19
/
STO 33
RCL 31
GTO "AA"
END
```

EFPA (EFFECTIVE FLAT PLATE AREA)

1. PURPOSE

This program determines the effective flat plate area of a design helicopter as a function of the following parameters: gross weight, clean or dirty lines, skid, fixed wheel, or retractable type landing gear. The formula used in the determination of the EFPA is:

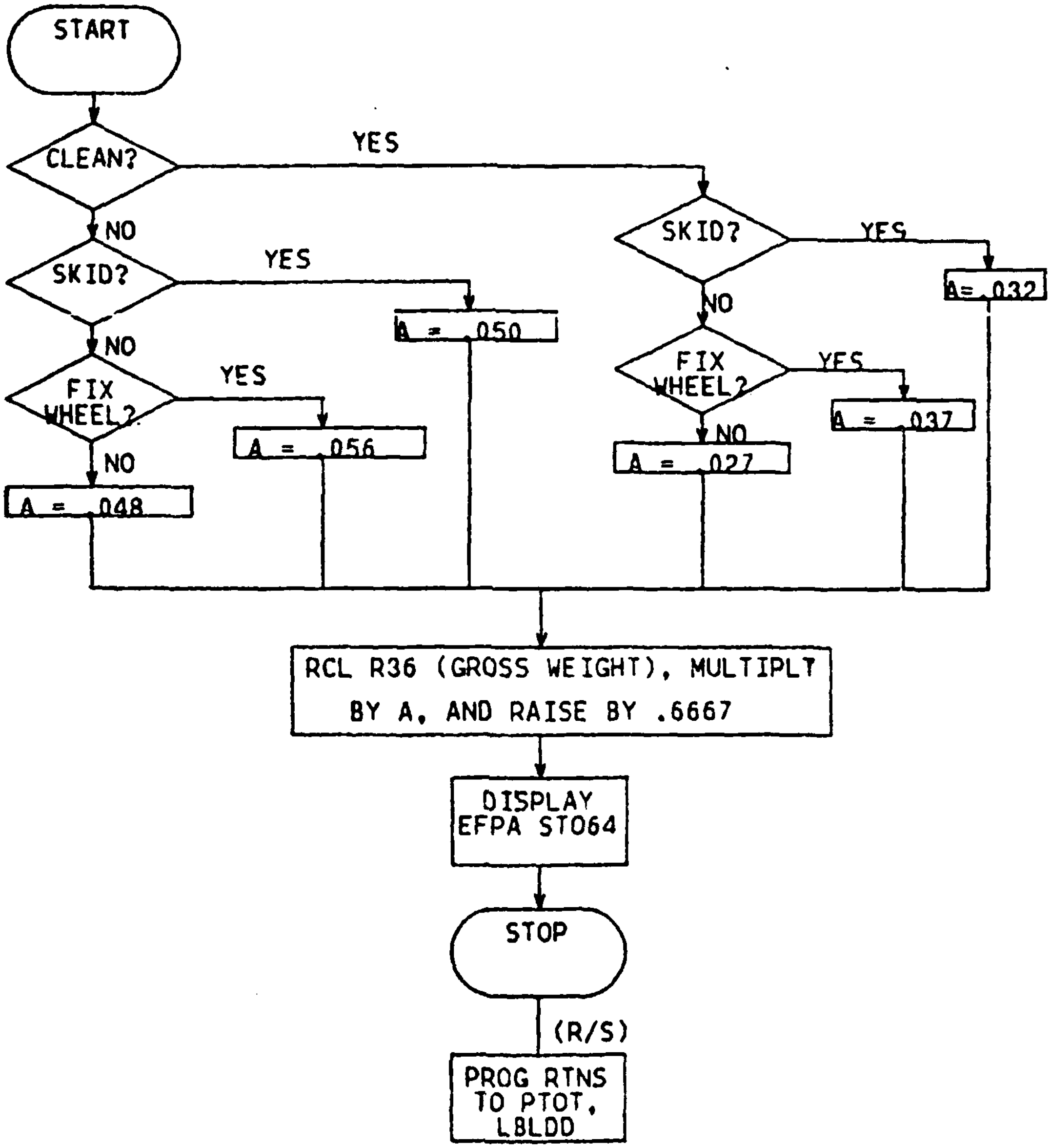
EFPA = (A) * (GW)**.66667 where the coefficient (A) is determined as shown below.

	SKID	FIXED	RETRACTABLE
CLEAN CONFIGURATION	.032	.037	.027
DIRTY CONFIGURATION	.050	.056	.046

These figures were computed through an iterative procedure of comparing the known EFPA values of production aircraft and their gross weights to values computed with the above formula. A degree of accuracy to within 10% can be achieved using these coefficients. It is left to the user to determine if his design is clean or dirty (i.e., is the design streamlined or does it contain numerous wing stores, flat plate canopy, etc.).

2. EQUATIONS (See above)

3. FLOWCHART (EFPA)



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS:

A) Determine the effective flat plate area of a helicopter with the following specifications:

Configuration: Dirty

Gross Weight: 14500 lbs

Landing Gear: Fixed wheel

Note: To run EFPA independent of the main program, the desired gross weight must be inputted manually into Register 36. This is done automatically when execution of the main program is performed.

KEYSTROKES		DISPLAY
14500 STO	36	14500
XEQ (alpha)	EFPA (alpha)	CLEAN?
0	(r/s)	SKID?
0	(r/s)	FIX WHEEL?
1	(r/s)	EFPA=33.3

The above specifications were from the AAH-64 Attack Helicopter whose actual EFPA is 33 sq ft. The computed EFPA differs by .9%.

B) Determine the EFPA of a helicopter with the following specifications:

Configuration: Clean

Gross Weight: 2150 lbs

Landing Gear: Skid

KEYSTROKES		DISPLAY
2150 STO 36		2150
XEQ (alpha) EFPA (alpha)		CLEAN?
1	(r/s)	SKID?
1	(r/s)	EFPA=5.33

Again, the above specifications represent a production aircraft, the OH6A, whose actual EFPA is 5.4 sq ft. The computed value differs by 1.3%.

5. PROGRAM LISTING

```
01♦LBL "EFPA"
02 FIX 2
03 "CLEAN?"
04 PROMPT
05 X>0?
06 GTO 01
07 "SKID?"
08 PROMPT
09 X>0?
10 GTO 02
11 "FIX WHEEL?"
12 PROMPT
13 X>0?
14 GTO 03
15 .048
16 GTO 10
17♦LBL 01
18 "SKID?"
19 PROMPT
20 X>0?
21 GTO 04
22 "FIX WHEEL?"
23 PROMPT
24 X>0?
25 GTO 05
26 .027
27 GTO 10
28♦LBL 02
29 .050
30 GTO 10
31♦LBL 03
32 .056
33 GTO 10
34♦LBL 04
35 .032
36 GTO 10
37♦LBL 05
38 .037
39♦LBL 10
40 RCL 36
41 .66667
42 Y↑X
43 *
44 "EFPA="
45 ARCL X
46 AVIEW
47 STO 64
48 STOP
49 GTO "DD"
50 END
```

DENSITY (RHO)

1. PURPOSE

This program computes the density of the air at a specified pressure altitude and temperature. In so doing, the program automatically calculates, but does not display, the density altitude and stores this value in Register ten. The equation used for this calculation is based upon the standard ICAO atmosphere and is accurate to an altitude of 36,089 ft.

2. EQUATIONS

RHO= RHO(SSL) * (1 - (K) * (H))**4.2561

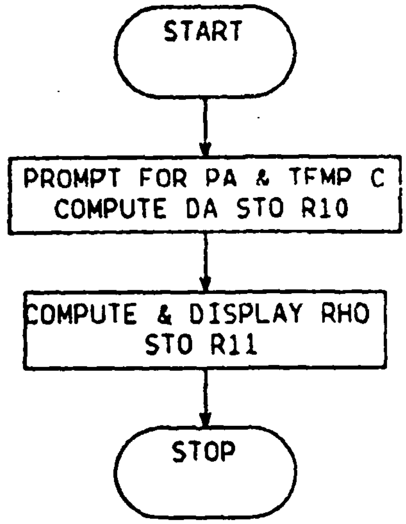
where:

RHO(SSL) is the density of the air at standard sea level which is equal to 0.0023769 (lb sec**2/ft**4).

K= 6.875 * 10**-6

H= density altitude (ft)

3. FLOWCHART (RHO)



AD-A136 026 COMPUTER PROGRAM FOR PRELIMINARY HELICOPTER DESIGN(U) 2/2
NAVAL POSTGRADUATE SCHOOL MONTEREY CA M W ROGERS
SEP 83

UNCLASSIFIED F/G 1/3 NL

END
DATE
FILMED
1 84
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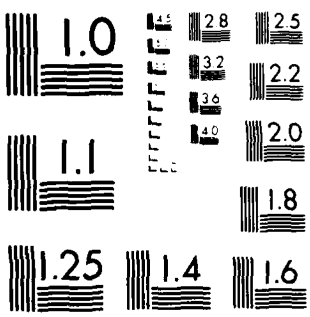


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

4. EXAMPLE PROBLEM AND USER INSTRUCTIONS:

Find the density and density altitude when the pressure altitude is 0.0 ft and the temperature is 15 deg. C.

KEYSTROKES		DISPLAY
XEQ (alpha)	RHO (alpha)	PA=?
0	(r/s)	TEMP C=?
15	(r/s)	2.38 -03

To find the density altitude simply recall Register 10 (-1.19).

5. PROGRAM LISTING

```
01♦LBL "RHO"
02 "PA=?"
03 PROMPT
04 6.875 E-06
05 *
06 CHS
07 1
08 +
09 5.2561
10 Y↑X
11 "TEMP C=?"
12 PROMPT
13 273.15
14 +
15 STO 18
16 /
17 288.16
18 *
19 .23496
20 Y↑X
21 CHS
22 1
23 +
24 6.875 E-06
25 /
26 STO 10
27 6.875 E-06
28 *
29 CHS
30 1
31 +
32 ENTER↑
33 4.2561
34 Y↑X
35 .0023769
36 *
37 STO 11
38 END
```

REGISTER FILE

REGISTER NUMBER------------------INFORMATION IN REGISTER

00--------------------------------Landing Gear Information

01--------------------------------Aspect Ratio (tr)

02--------------------------------Cdo (tr)

03--------------------------------Mach Crit

04--------------------------------Chord Main Rotor (c)

05--------------------------------Radius Main Rotor (r)

06--------------------------------# main rotor blades (b)

07--------------------------------Cdo (mr)

08--------------------------------Rotational Vel mr (rv)

09--------------------------------Control # (printer)

10--------------------------------Density Altitude (da)

11--------------------------------RHO

12--------------------------------Area mr (A)

13--------------------------------Tip Velocity (Vt)

14--------------------------------Coeff of Thrust mr (CT)

15--------------------------------Tip Loss Factor mr (B)

16--------------------------------Pi (oge) mr

17--------------------------------H/D

18--------------------------------Temperature (c to k)

19--------------------------------Solidity mr (SD)

20--------------------------------Induced Vel hover (Vi)

21---------------------------------Profile Power hover (Po)

22---------------------------------Total Power mr fwd (Pt fwd)

23---------------------------------Max Fwd Vel

24---------------------------------Profile Power fwd (Po mr)

25---------------------------------Forward Velocity (Vf)

26---------------------------------Induced tr Vel (portion)

27---------------------------------Induced Power (mr fwd)

28---------------------------------Parasite Power (Pp)

29---------------------------------Solidity (tr)

30---------------------------------Total Power (mr oge)

31---------------------------------Disk Loading (DL)

32---------------------------------Aspect Radio (AR)

33---------------------------------Coefficient of Lift (CL)

34---------------------------------Total Power (mr ige)

35---------------------------------Empty Weight (WE)

36---------------------------------Gross Weight (GW)

37---------------------------------Tip Mach # (mr)

38---------------------------------Induced Power (mr ige)

39---------------------------------Max GW (specification)

40---------------------------------Length of Tail (L tr)

41---------------------------------Thrust of tr

42---------------------------------Radius of tr (R)

43---------------------------------Area of tr (A)

44---------------------------------Tip Vel tr (Vt)

45---------------------------------Coeff of Thrust tr (CT)

46---------------------------------MD

47--------------------------------Tip Loss Factor tr (B)

48--------------------------------Pi(tl-tr) hover SSL oge

49--------------------------------Po(tr) hover SSL oge

50--------------------------------Pt(tr) hover SSL oge

51--------------------------------MU (tr)

52--------------------------------Profile Power (tr fwd)

53--------------------------------Thrust (tr fwd)

54--------------------------------CT (tr fwd)

55--------------------------------B (tr fwd)

56--------------------------------Pi (tl-tr-fwd)

57--------------------------------Pt (tr-fwd)

58--------------------------------Chord tr (c)

59--------------------------------# tr Blades (b)

60--------------------------------Tip Mach (tr)

61--------------------------------Pi total (mr+tr)

62--------------------------------Po total (mr+tr)

63--------------------------------PTOT (mr+tr)

64--------------------------------EFPA

65--------------------------------Skid Gear Weight

66--------------------------------Fixed Wheel Gear Wt

67--------------------------------No. of Engines

APPENDIX B

EXAMPLE/PROGRAM VALIDATION PROBLEMS

PRELIMINARY DESIGN OF A CARGO HELICOPTER

The student is tasked to design a heavy cargo helicopter. A determination must be made as to the most practical type landing gear to be utilized in the design. The following specifications are provided:

Maximum Allowable Gross Weight	40,000 lbs
Maximum Rotor Diameter:	76 ft
Maximum Velocity:	180 kts
Useful Load:	9000 lbs
Fuel Weight:	4500 lbs
Height of Rotor Above the Ground:	16 ft
Cdo Main Rotor:	.01
Cruise Velocity:	150 kts
Tail Rotor Aspect Ratio (4.5 - 8.0):	6.5
Cdo Tail Rotor (1.25 Cdo mr<Cdo tr<1.5 Cdo mr):	.0145
No. of Tail Rotor Blades:	4.0
No. of Main Rotor Blades:	6.0
Critical Mach Number:	.65
Number of Landing Gear:	4.0
Number of Engines:	2.0

In an effort to eliminate unnecessary repetition, the user is advised to refer to the individual program summaries

for a more detailed description. Before proceeding further with this problem, the user must clear all flags and load MR, PHV, FM, CHD, RV, RHO, WT, and EFPA.

KEYSTROKES		DISPLAY
XEQ (alpha) SIZE (alpha)		SIZE---
068		0.00
XEQ (alpha) MR (alpha)		Spec Wt=?
40,000	(r/s)	R=?
38	(r/s)	Mch Crit=?
0.65	(r/s)	Vt max= 725.6
	(r/s)	Vf max=?
180	(r/s)	DL=7.054
	(r/s)	RV=19.095
	(r/s)	CT= .006
	(r/s)	SD= .066
	(r/s)	c= 1.97
	(r/s)	AR= 19.28
	(r/s)	CL= .512
	(r/s)	R ok?
1	(r/s)	No. MR Blds?
6	(r/s)	Cdo mr=?
0.01	(r/s)	Pth oge= 2900
	(r/s)	H=?
16	(r/s)	Pth ige= 2305
	(r/s)	FIG MER= 0.73
	(r/s)	FM OK?

1	(r/s)	WE= 24,000
	(r/s)	Wb= 2516.35
	(r/s)	Wh= 1492.98
	(r/s)	Wp= 3479.66
	(r/s)	Wf= 5040.00
	(r/s)	Wc= 1440.00
	(r/s)	We= 1440.00
	(r/s)	Wq= 6720.00
	(r/s)	WE 2= 22,128.99
	(r/s)	W FL?
4500	(r/s)	USE LD?
9000	(r/s)	SKID?
1	(r/s)	MR>2 blds?
1	(r/s)	TGW= 36,311.5
	(r/s)	WT OK?
1	(r/s)	R=?
38	(r/s)	Mch Crit=?
0.65	(r/s)	Vt Mx= 725.62
	(r/s)	Vf Mx=?
180	(r/s)	DL= 8.004
	(r/s)	RV= 19.095
	(r/s)	CT= .006
	(r/s)	SD= .075
	(r/s)	c= 2.236
	(r/s)	AR= 16.996
	(r/s)	CL= .512

	(r/s)	R OK?
1	(r/s)	NO MR blds?
6	(r/s)	Cdo mr=?
0.01	(r/s)	Pth oge= 3463
	(r/s)	H=?
16	(r/s)	Pth ige= 2743
	(r/s)	FIG MER= 0.75
	(r/s)	FM OK?
1	(r/s)	Clr MR,PHV,FM,CHD,RV
	(r/s)	Input PTOT,PCOMP,ESHP
XEQ (alpha) CLP (alpha)		CLP-
(alpha) MR (alpha)		1.0

Continue for PHV, FM, CHD, and RV. Input PCOMP and ESHP. If a printer is to be used, connect it after inputting the appropriate PTOT program. For this example, a printer will be used.

XEQ (alpha) PTOT (alpha)		INPUT CNT NO.
0.18020	(r/s)	PA=?
0	(r/s)	TEMP C=?
15	(r/s)	AR tr=?
6.5	(r/s)	No. tr Blds?
4	(r/s)	Cdo tr=?
0.0145	(r/s)	EFPA KNOWN?
0	(r/s)	CLEAN?
0	(r/s)	SKID?

1	(rs)	EFPA= 54.83
	(r/s)	No. Engs=?
2	(r/s)	

For this example, the power requirements are applicable to standard sea level conditions (0 pa, 15 deg C). The user may, of course, use any altitude. The aircraft, being of the cargo type, will probably not have clean lines. For this first iteration, a skid gear is used. Recall that the skid is used as a base for the fixed and retractable type gears. The control number (.18020) was selected because the maximum velocity of the aircraft is 180 knots and 20 knots is a suitable increment. Note how the printer outputs the power required at specific velocities. Once the printer signals the completion of the program, the user re-executes the "WT" program.

XEQ (alpha) WT (alpha)		W FL?
4500	(r/s)	USE LD?
9000	(r/s)	SKID?
0	(r/s)	NO. LG?
4	(r/s)	FX GR?
1	(r/s)	T GW= 37209.57
	(r/s)	INPUT CNT NO.
0.18020	(r/s)	EFPA KNOWN?
0	(r/s)	CLEAN?
0	(r/s)	SKID?

0	(r/s)	FIX WHEEL?
1	(r/s)	EFPA= 62.42
	(r/s)	NO. ENGS=?
2	(r/s)	

The printer now displays the power required from 0 to 180 knots, incremented every 20 knots.

XEQ (alpha)	WT (alpha)	W FL?
4500	(r/s)	USE LD?
9000	(r/s)	SKID?
0	(r/s)	NO. LG?
4	(r/s)	FX GR?
0	(r/s)	T GW= 37464.62
	(r/s)	INPUT CNT NO.
0.18020	(r/s)	EFPA KNOWN?
0	(r/s)	CLEAN?
0	(r/s)	SKID?
0	(r/s)	FIX WHEEL?
0	(r/s)	EFPA= 53.74
	(r/s)	NO. ENGS=?
2	(r/s)	

The printer now displays the power required for the aircraft with a retractable landing gear.

SKID	FIXED WHEEL	RETRACTABLE GEAR

SKID

```
TOTAL POWER

GW=36311.5125
EFPA=54.83

VEL (KNOTS)
ESHP
            0    ***
         4247    ***

           20    ***
         3721    ***

           40    ***
         2843    ***

           60    ***
         2638    ***

           80    ***
         2817    ***

          100    ***
         3283    ***

          120    ***
         4018    ***

          140    ***
         5039    ***

          160    ***
         6374    ***

          180    ***
         8059    ***
```

FIXED WHEEL

```
TOTAL POWER

GW=37209.57
EFPA=62.42

VEL (KNOTS)
ESHP
            0    ***
         4376    ***

           20    ***
         3843    ***

           40    ***
         2943    ***

           60    ***
         2727    ***

           80    ***
         2918    ***

          100    ***
         3419    ***

          120    ***
         4215    ***

          140    ***
         5324    ***

          160    ***
         6779    ***

          180    ***
         8622    ***
```

RETRACTABLE GEAR

```
TOTAL POWER

GW=37464.62
EFPA=53.74

VEL (KNOTS)
ESHP
            0    ***
         4413    **

           20    *
         3876    *

           40    *
         2963    *

           60    ***
         2724    ***

           80    ***
         2880    ***

          100    ***
         3328    ***

          120    ***
         4047    ***

          140    ***
         5049    ***

          160    ***
         6362    ***

          180    ***
         8021    ***
```

From the above data, the user can readily see that, at a hover, The helicopter configured with the skid gear requires less power due to the gear's reduced weight. As forward speed increases, however, the effective flat plate area value (parasite drag) begins to affect power requirements. The skid configured aircraft always requires less power than the fixed wheel aircraft due to its lighter weight and smaller EFPA value.

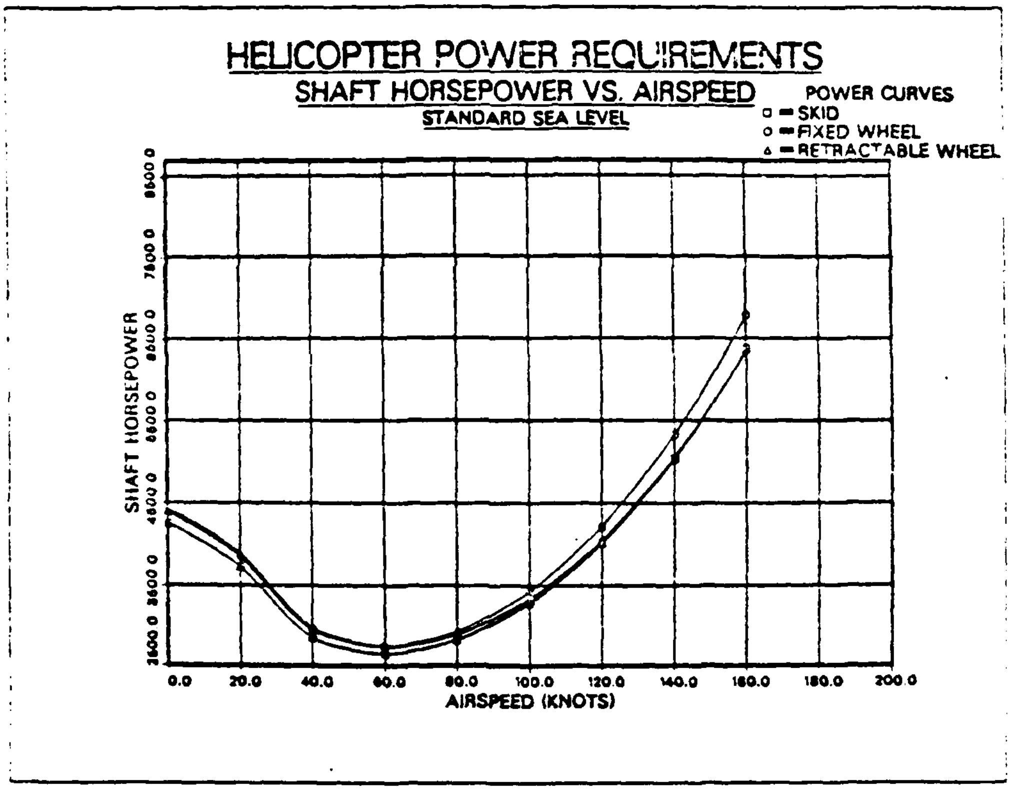
The benefits of the retractable gear's reduced drag versus the skid gear's lighter weight are not appreciated until the aircraft attains its designed cruise velocity of one hundred and fifty knots. Since the aircraft will certainly be flying at or below cruise velocity more than above this speed, it seems logical that a skid type gear should be employed in the design. This logic begins to lose its validity when it is understood that heavy cargo helicopters are often not capable of performing a hovering type take-off, as would be required with skid gear.

The environment these aircraft operate in (heavy loads and oftentimes high density altitude) results in rolling take-offs being used to keep within engine and transmission limitations. The question of skid versus wheel type gear is therefore academic when heavy cargo helicopters are concerned.

When comparing the fixed and retractable data, it is apparent that at approximately 60 knots the retractable geared aircraft begins to require less power even though that

aircraft is heavier by more than two hundred pounds! Since the helicopter will be flying at speeds much greater than sixty knots, the most advantageous landing gear is the retractable type.

The landing gear data may be evaluated in graphical form by using the program "Myplot." The following is a graph of the preceding data.



The user might well want to know how much additional velocity could be attained by using the retractable type gear as opposed to the fixed wheel. From the data, 8622 hp is required to achieve the maximum forward velocity using the fixed wheel gear, 601 more horsepower than the helicopter with the retractable gear. If power is the limiting factor, it is a simple matter to convert the 601 excess hp into velocity.

KEYSTROKES		DISPLAY
XEQ (alpha) PTOT (alpha)		INPUT CNT NO.
180.19001	(r/s)	EFPA KNOWN?
1	(r/s)	EFPA=?
53.74	(r/s)	

The printer computes the power required from 180 to 190 knots in increments of 1 hp.

```
TOTAL POWER

GW=37465
EFPA=?
            54  ***

VEL <KNOTS>
ESHP

           180  ***
          8020  ***

           181  ***
          8113  ***

           182  ***
          8207  ***

           183  ***
          8301  ***

           184  ***
          8397  ***

           185  ***
          8493  ***

           186  ***
          8591  ***

           187  ***
          8690  ***

           188  ***
          8789  ***

           189  ***
          8890  ***

           190  ***
          8991  ***
```

From the data, 8622 horsepower is required at approximately 186.5 knots. By using the retractable gear, the maximum velocity has been increased by over five knots.

HUGHES AAH-64 DESIGN COMPARISON

The following data is from the AAH-64 helicopter:

Specification weight:	17,640 lbs
Critical mach #:	.65
Fuel weight:	1600 lbs
Useful load:	4351 lbs
Max. fwd. vel.	155 knots
Main rotor diameter:	48 ft
Cdo main rotor:	.01
Cdo tail rotor:	.01
No. main rotor blades:	4
No. tail rotor blades:	4
Configuration:	Dirty
No. of engines	2
No. of landing gear:	3
Height of rotor above grd:	12.59 ft
Aspect ratio, tr	5.53

Using the above data and the procedure of the example problem, the following power results were attained:

SKID

TOTAL POWER

GW=15,785.3026
EFPA=31.46

VEL (KNOTS)
ESHP

0.	***
1,890.	***
20.	***
1,667.	***
40.	***
1,280.	***
60.	***
1,174.	***
80.	***
1,252.	***
100.	***
1,476.	***
120.	***
1,839.	***
140.	***
2,351.	***
160.	***
3,029.	***
180.	***
3,893.	***

FIXED WHEEL

TOTAL POWER

GW=16,236.47
EFPA=35.91

VEL (KNOTS)
ESHP

0.	***
1,958.	***
20.	***
1,731.	***
40.	***
1,334.	***
60.	***
1,223.	***
80.	***
1,309.	***
100.	***
1,553.	***
120.	***
1,952.	***
140.	***
2,516.	***
160.	***
3,265.	***
180.	***
4,222.	***

RETRACTABLE GEAR

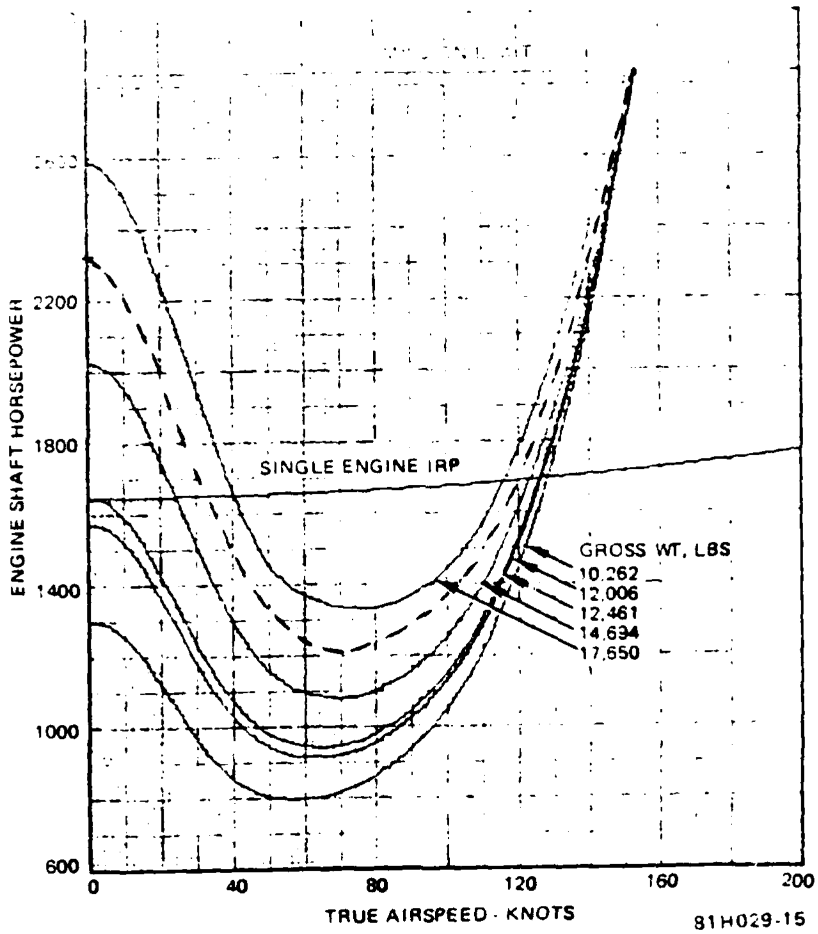
TOTAL POWEF

GW=16,363.17
EFPA=30.94

VEL (KNOTS)
ESHP

0.	***
1,977.	***
20.	***
1,749.	***
40.	***
1,345.	***
60.	***
1,221.	***
80.	***
1,287.	***
100.	***
1,501.	***
120.	***
1,855.	***
140.	***
2,358.	***
160.	***
3,025.	***
180.	***
3,675.	***

The Hughes AAH-64 utilizes a fixed wheel type landing gear. The airspeed vs. power graph depicts the actual power requirements of the AAH-64 at various airspeeds and weights.



By approximating the computed gross weight line for the fixed wheel gear data (16,236.47 lbs), a comparison between the actual and computed power requirements can be made. The following table shows this comparison and the percent error.

VEL	HP ACTUAL	HP COMPUTED	|% ERROR|
0	2320	1958	15.6
20	2000	1731	13.5
40	1500	1334	11.1
60	1220	1223	0.2
80	1220	1309	7.3
100	1375	1553	12.9
120	1680	1952	16.2
140	2300	2516	9.4

The average percent error is 10.15

COMPARISON OF ADV. SYST. COMPUTER PROGRAM

One of the primary goals of this project is to develop programs for the HP-41 which output values to within 10 percent of the Army Aviation Research and Development Command's Advanced System's Computer Program. The following data was inputted into both programs.

Radius of main rotor blade=	27 ft
Critical mach number=	.65
Maximum fwd. velocity=	160 knots
Specification weight=	18000 lbs
No. of main rotor blades=	4
Coefficient of drag at 0 lift=	.01
Height of rotor above ground=	14.4 ft
Fuel weight=	4000 lbs
Useful load=	3750 lbs
Tail rotor aspect ratio=	8.0
Coeff of drag at 0 lift (tr)=	.0145
No. of tail rotor blades=	4
Configuration=	Clean
No. of engines=	2
No. of landing gear=	3

Using the PTOT (printer) program, the following data was outputted:

SKID	FIXED WHEEL	RETRACTABLE GEAR
TOTAL POWER	TOTAL POWER	TOTAL POWER
GW=16744.9881	GW=17198.23	GW=17326.65
EFPA=20.95	EFPA=24.65	EFPA=18.08
VEL (KNOTS)	VEL (KNOTS)	VEL (KNOTS)
ESHP	ESHP	ESHP
0 ***	0 ***	0 ***
1861 ***	1923 ***	1941 ***
20 ***	20 ***	20 ***
1608 ***	1666 ***	1682 ***
40 ***	40 ***	40 ***
1204 ***	1251 ***	1258 ***
60 ***	60 ***	60 ***
1107 ***	1149 ***	1141 ***
80 ***	80 ***	80 ***
1173 ***	1221 ***	1138 ***
100 ***	100 ***	100 ***
1356 ***	1421 ***	1348 ***
120 ***	120 ***	120 ***
1647 ***	1741 ***	1610 ***
140 ***	140 ***	140 ***
2049 ***	2187 ***	1976 ***
160 ***	160 ***	160 ***
2576 ***	2772 ***	2453 ***

A comparison of the Advanced System's output reveals the following:

VEL	SKID			FIX WHEEL			RETR GEAR		
	HP41	AD SY	|%ER|	HP41	AD SY	|%ER|	HP41	AD SY	|%ER|
0	1861	1998	6.86	1923	2065	6.88	1941	2085	6.91
20	1608	1781	9.71	1666	1846	9.75	1682	1865	9.81
40	1204	1344	10.42	1251	1396	10.39	1258	1406	10.53
60	1107	1152	3.91	1149	1198	4.09	1141	1193	4.36
80	1173	1143	2.62	1221	1194	2.26	1188	1166	1.89
100	1356	1264	7.28	1421	1330	6.84	1348	1269	6.23
120	1647	1508	9.22	1741	1621	7.40	1610	1498	7.48
140	2049	1984	3.28	2187	2147	1.86	1976	1956	1.02
160	2576	2688	4.17	2772	2780	.28	2453	2628	6.66

Skid avg % error= 6.39

Fixed wheel avg % error= 5.53

Retr gear avg % error= 6.10

It is readily apparent that the goal of 10% accuracy has been exceeded. These programs are rapidly executed, inexpensive to run, and sacrifice a very small percentage of accuracy.

The following printouts depict the Advanced System's Branch computer output for Skid, Fixed Wheel, and Retractable Type landing gears.

UTILITY DESIGN, SKID LANDING GEAR
TEST CASE FOR MIKE ROGERS

POWER REQUIRED VERSUS FORWARD SPEED

GROSS WEIGHT = 14745.LB [illegible] VMCP=1[illegible]2.[illegible]KT SHAFT/[illegible]

SPEED (KTS)	0.	20.	40.	60.	[illegible]	100.	120.	140.	[illegible]
HPIND	1363.	1197.	783.	540.	424.	334.	282.	245.	219.
HPPRO	357.	359.	364.	377.	401.	424.	464.	[illegible]	[illegible]
HPPAR	0.	-10.	13.	73.	171.	311.	495.	709.	937.
HPPROP	0.	0.	0.	0.	0.	0.	[illegible]	0.	[illegible]
HPCOMP	0.	0.	0.	1.	4.	34.	99.	232.	444.
HPSTAL	0.	0.	0.	0.	0.	[illegible]	0.	102.	[illegible]
HPTR	155.	123.	63.	51.	43.	53.	55.	69.	[illegible]
HPLOSS	72.	67.	64.	[illegible]	60.	64.	71.	75.	75.
HPACC	53.	53.	53.	53.	53.	53.	53.	53.	53.
HP REQUIRED	[illegible]	1732.	1244.	[illegible]	[illegible]	[illegible]	1503.	[illegible]	[illegible]
HP AVAILABLE	2323.	[illegible]	2324.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ENG AVAILABLE	3229.	3033.	3330.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUEL (LB/HR)	1272.	981.	813.	744.	747.	785.	878.	[illegible]	[illegible]
NM/LB-FUEL	0.0	0.0203	[illegible]	[illegible]	0.1071	0.1274	0.1367	[illegible]	[illegible]
[illegible]	26.7	25.1	23.3	22.3	21.5	[illegible]	21.5	21.5	21.6
ADV RATIO	0.0	[illegible]	0.093	0.140	[illegible]	0.233	0.279	0.325	0.371
TPP ANGLE	0.0	-1.6	0.4	1.4	2.4	3.4	4.6	5.6	[illegible]
LONG. FLAP	0.0	[illegible]	2.7	2.4	2.1	1.5	0.6	0.1	[illegible]
FUS ANGLE	0.0	2.6	[illegible]	1.2	[illegible]	[illegible]	-0.4	-0.7	[illegible]
FUSELAGE LIFT	0.	0.	11.	[illegible]	[illegible]	35.	40.	44.	[illegible]
H TAIL LIFT	0.	3.	11.	[illegible]	-23.	-77.	-155.	[illegible]	-374.
WING LIFT	0.	0.	0.	0.	0.	0.	0.	0.	0.
[illegible]	0.	-167.	110.	[illegible]	[illegible]	[illegible]	1347.	[illegible]	[illegible]
AUX [illegible]	0.	0.	0.	0.	0.	0.	0.	0.	0.
PROP [illegible]	[illegible]	[illegible]	0.00	[illegible]	0.00	[illegible]	0.00	[illegible]	[illegible]
[illegible]	[illegible]	0.5	[illegible]	[illegible]	[illegible]	-1.0	-1.4	[illegible]	[illegible]
ROTOR LIFT	[illegible]	[illegible]	[illegible]	[illegible]	15742.	15787.	[illegible]	[illegible]	[illegible]
ROTOR THRUST	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16911.	[illegible]	[illegible]
L/D (ROTOR)	[illegible]	[illegible]	1.73	3.33	5.00	5.47	[illegible]	[illegible]	[illegible]
L/D TOTAL	0.00	[illegible]	1.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

UTILITY DESIGN, FIXED WHEEL [illegible]

TEST CASE [illegible]

POWER REQUIRED VERSUS FORWARD SPEED

GROSS WEIGHT = 17233.LB [illegible] [illegible] SAFETY [illegible]

SPEED (KNOTS)	0.	20.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPIND	1413.	1231.	930.	575.	437.	363.	[illegible]	[illegible]	[illegible]
HPPRO	302.	302.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPPAR	0.	-11.	15.	[illegible]	130.	347.	[illegible]	[illegible]	[illegible]
[illegible]	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPCMP	0.	0.	0.	1.	9.	35.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPTR	[illegible]	125.	72.	53.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	72.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPACC	53.	53.	53.	53.	53.	53.	53.	53.	[illegible]
HP REQUIRED	[illegible]	1546.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HP AVAILABLE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3030.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUEL (LB/HR)	[illegible]	[illegible]	[illegible]	741.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DRAG AREA	24.7	[illegible]	27.2	26.3	[illegible]	25.5	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TPP ANGLE	0.0	-0.6	0.4	1.4	[illegible]	3.7	[illegible]	[illegible]	[illegible]
[illegible] FLAP	[illegible]	[illegible]	2.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUS ANGLE	[illegible]	[illegible]	[illegible]	1.1	[illegible]	-0.2	[illegible]	[illegible]	[illegible]
[illegible] LIFT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31.	[illegible]	[illegible]	[illegible]
H TAIL LIFT	[illegible]	[illegible]	[illegible]	2.	-32.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] LIFT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] PROP [illegible]	[illegible]	-175.	[illegible]	[illegible]	753.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PROP EFF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] LIFT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L/D ([illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L/D ([illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

UTILITY [illegible]

[illegible]

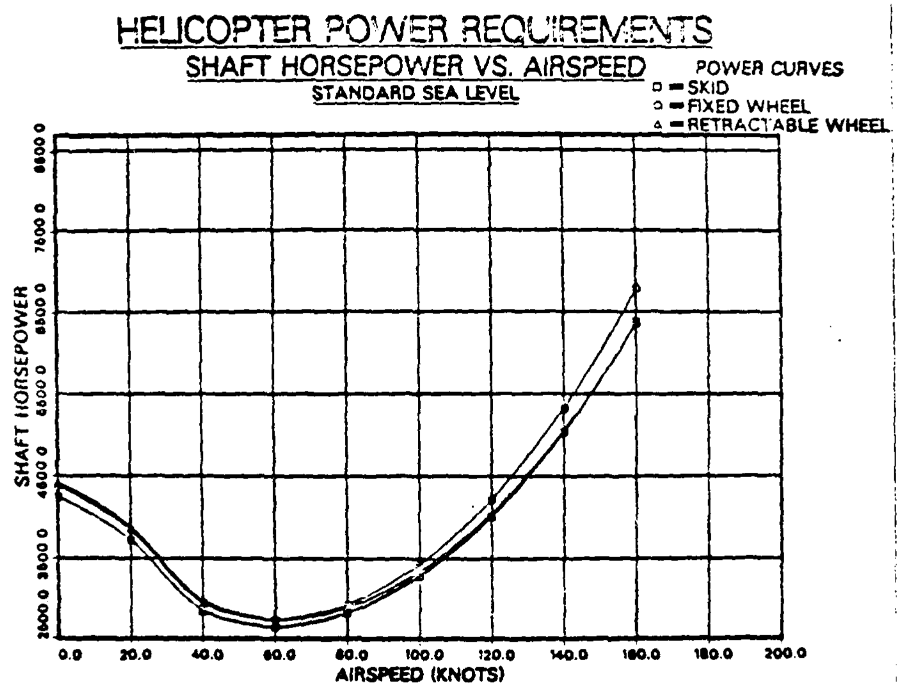
GROSS WEIGHT = 17377.[illegible]									
SPEED (KTS)	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPIND	1435.	1267.	742.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPP[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPPAR	0.	-12.	10.	[illegible]	158.	234.	[illegible]	[illegible]	[illegible]
HPP[illegible]	0.	[illegible]	0.	[illegible]	0.	[illegible]	0.	[illegible]	0.
HPCMPT	0.	0.	0.	1.	9.	35.	101.	[illegible]	[illegible]
HPSTAL	0.	0.	0.	0.	0.	[illegible]	3.	127.	[illegible]
HPTR	[illegible]	175.	72.	53.	50.	51.	57.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HPACC	[illegible]	53.	57.	53.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HP REQUIRED	[illegible]	[illegible]	1405.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HP AVAILABLE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FUEL (LB/HR)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	737.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	20.[illegible]	19.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TPP ANGLE	[illegible]	[illegible]	0.3	1.2	2.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	-0.4	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] TAIL LIFT	[illegible]	[illegible]	[illegible]	[illegible]	-15.	-61.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.	[illegible]	[illegible]	[illegible]	637.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PROP [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17351.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L/D [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.44	[illegible]	[illegible]	[illegible]
L/D [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX C

COMPUTER GRAPHICS PRINTOUT

MYPLOT AND POWERPLO COMPUTER PRINTOUTS

The following program graphs the power data for a skid, fixed wheel, and retractable geared configured helicopter. The attached graph is an actual plot of the example cargo helicopter.



FILE: MYPLOT FORTRAN A1 NAVAL POSTGRADUATE SCHOOL

```
C      PROGRAM TO PLOT POWER REQUIREMENTS VS. AIRSPEED FOR A HELICOPTER
C      WITH SKID, FIXED WHEEL, AND RETRACTABLE LANDING GEAR USING THE
C      TEXTRONIX ELECTROSTATIC PLOTTER AND DISSPLA SOFTWARE.
C
       REAL   SKID,SKIDS,FIX,FIXED,RETR,RETRA
C
       DIMENSION SKID(10),SKIDS(10),FIX(10),FIXED(10),RETR(10),RETRA(10)
C
       DATA  SKID/0.,20.,40.,60.,80.,100.,120.,140.,160.,180./
       DATA  SKIDS/4247,3721,2843,2538,2817,3233,4015,5039,6374,8059/
       DATA  FIX/0.,20.,40.,60.,80.,100.,120.,140.,160.,180./
       DATA  FIXED/4376,3843,2943,2727,2918,3419,4215,5324,6779,8622/
       DATA  RETR/0.,20.,40.,60.,80.,100.,120.,140.,160.,180./
       DATA  RETRA/4413,3876,2963,2724,2880,3328,4047,5049,6562,8021/
C CALL TEKTRONIX 618 PLOTTER
       CALL  TEK618
C IF PLOT EXCEEDS SCREEN SIZE, SCALE DOWN TO FIT SCREEN
       CALL  HWSCAL('SCREEN')
C SET PAGE SIZE
       CALL  PAGE(11.,8.5)
C DEFINE AREA OF PLOT ON PAGE
       CALL  AREA2D( 8.0,5.5)
C FRAME THE SUBPLOT AREA
       CALL  FRAME
C SET THE TYPE FONT DESIRED
       CALL  SWISSL
C SET THICKNESS OF CURVE (IN INCHES)
       CALL  THKCRV(.015)
C DEFINE NAME OF X AXIS
       CALL  XNAME('AIRSPEED (KNOTS)$',100)
C DEFINE NAME OF Y AXIS
       CALL  YNAME('SHAFT HORSEPOWER$',100)
C DEFINE HEADING OF PLOT
       CALL  HEADIN('HELICOPTER POWER REQUIREMENTS$',-100,2.0,3)
       CALL  HEADIN('SHAFT HORSEPOWER VS. AIRSPEED$',-100,1.5,3)
       CALL  HEADIN('STANDARD SEA LEVEL$',-100,1.0,3)
C SET X ORIGIN, X STEP, X MAXIMUM, Y ORIGIN, Y STEP, Y MAXIMUM
       CALL  GRAF(0.0,20.,200.,2500.,1000.,8700.)
       CALL  RASPLN (1.5)
       CALL  GRID(1,1)
C      CALL  CURVE(IPTSX,TPTSY,          ,0)
       CALL  CURVE(SKID,SKIDS,9,1)
       CALL  CURVE(FIX,FIXED,9,1)
       CALL  CURVE(RETR,RETRA,9,1)
       CALL  LINES('SKIDS$',IPAK1,1)
       CALL  LINES('FIXED WHEELS$',IPAK1,2)
       CALL  LINES('RETRACTABLE WHEELS$',IPAK1,3)
       CALL  MYLEGN('POWER CURVES',12)
       CALL  LEGEND(IPAK1,3,6.6,5.5)
       CALL  ENDPL(0)
       CALL  DONEPL
       STOP
       END
```

The following program plots the data from the PTOT (Full Display) program.

FILE: POWERPLO FORTRAN A1 NAVAL POSTGRADUATE SCHOOL

```
C      PROGRAM TO PLOT THE PARASITE, PROFILE, INDUCED, AND TOTAL
C      POWER REQUIRED FOR A HELICOPTER WITH SKID, FIXED WHEEL, OR
C      RETRACTABLE LANDING GEAR.
C
       REAL   PAR,PARA,PRO,PROS,INC,INCU,TOT,TOTS
C
       DIMENSION PAR( ),PARA( ),PRO( ),PROS( ),IND( ),INDU( ),TOT( ),
      1TOTS( )
       DATA  PAR/0.,20.,40.,60.,80.,100.,120.,140.,160./
       DATA  PARA/                                                   /
       DATA  PRO/0.,20.,40.,60.,80.,100.,120.,140.,160./
       DATA  PROS/                                                   /
       DATA  IND/0.,20.,40.,60.,80.,100.,120.,140.,160./
       DATA  INDU/                                                   /
       DATA  TOT/0.,20.,40.,60.,80.,100.,120.,140.,160./
       DATA  TOTS/                                                      /
C CALL TEKTRONIX 618 PLOTTER
       CALL  TEK618
C IF PLOT EXCEEDS SCREEN SIZE, SCALE DOWN TO FIT SCREEN
       CALL  HWSCAL('SCREEN')
C SET PAGE SIZE
       CALL  PAGE(11.,8.5)
C DEFINE AREA OF PLOT ON PAGE
       CALL  AREA2D( 8.0,5.5)
C FRAME THE SUBPLOT AREA
       CALL  FRAME
C SET THE TYPE FONT DESIRED
       CALL  SWISSL
C SET THICKNESS OF CURVE (IN INCHES)
       CALL  THKCRV(.015)
C DEFINE NAME OF X AXIS
       CALL  XNAME('AIRSPEED (KNOTS)$',100)
C DEFINE NAME OF Y AXIS
       CALL  YNAME('SHAFT HORSEPOWER$',100)
C DEFINE HEADING OF PLOT
       CALL  HEADIN('HELICOPTER POWER REQUIREMENTS$',-100,1.5,3)
       CALL  HEADIN('SHAFT HORSEPOWER VS. AIRSPEED$',-100,1.0,3)
       CALL  HEADIN('SKID LANDING GEAR$',-100,1.0,3)
C      CALL  HEADIN('FIXED WHEEL$',-100,1.0,3)
C      CALL  HEADIN('RETRACTABLE GEAR$',-100,1.0,3)
C SET X ORIGIN, X STEP, X MAXIMUM, Y ORIGIN, Y STEP, Y MAXIMUM
       CALL  GRAF(0.0,20.,180.,0.,500.,2000.)
       CALL  RASPLN (1.5)
       CALL  GRID(1,1)
C      CALL  CURVE(TPTSX,TPTSY,          ,0)
       CALL  CURVE(PAR,PARA,9,1)
       CALL  CURVE(PRO,PROS,9,1)
       CALL  CURVE(IND,INDU,9,1)
       CALL  CURVE(TOT,TOTS,9,1)
       CALL  LINES('PARASITE$',IPAK1,1)
       CALL  LINES('PROFILE$',IPAK1,2)
       CALL  LINES('INDUCED$',IPAK1,3)
       CALL  LINES('TOTAL$',IPAK1,4)
       CALL  MYLEGN('POWER CURVES',12)
       CALL  LEGEND(IPAK1,4,6.6,6.0)
       CALL  ENDPL(0)
       CALL  DONEPL
       STOP
       END
```

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4. DISSPLA Pocket Guide, pp. 6-12, Integrated Software Systems Corporation, 1981.

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